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Welcome to

BOOK OF AIRCRAFT

The history of human aviation spans over a hundred years, from the first manned flight of the Wright Flyer in 1903, which flew a ground-breaking 260 metres, to the futuristic spacecraft of today that shuttle astronauts and payloads to the International Space Station. Today's aircraft are constantly evolving and being upgraded; would the Wright brothers even recognise a Eurofighter Typhoon as a descendant of their Flyer? In this new edition of How It Works Book of Aircraft, we will bring to life a plethora of modern flying machines. Find out what it takes to become a pilot for the Red Arrows and how the Supermarine Spitfire became such a successful aircraft in the Military section. Discover how commercial airliners are becoming more and more efficient and how hypersonic flight is being developed in the Commercial section. In the Spacecraft section we transport you to the outer reaches of space to search for life on distant planets and investigate how we may send humans to space. Enjoy the book!

BOOK OF AIRCRAFT

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HOW IT WORKS BOOK OF AIRCRAFT

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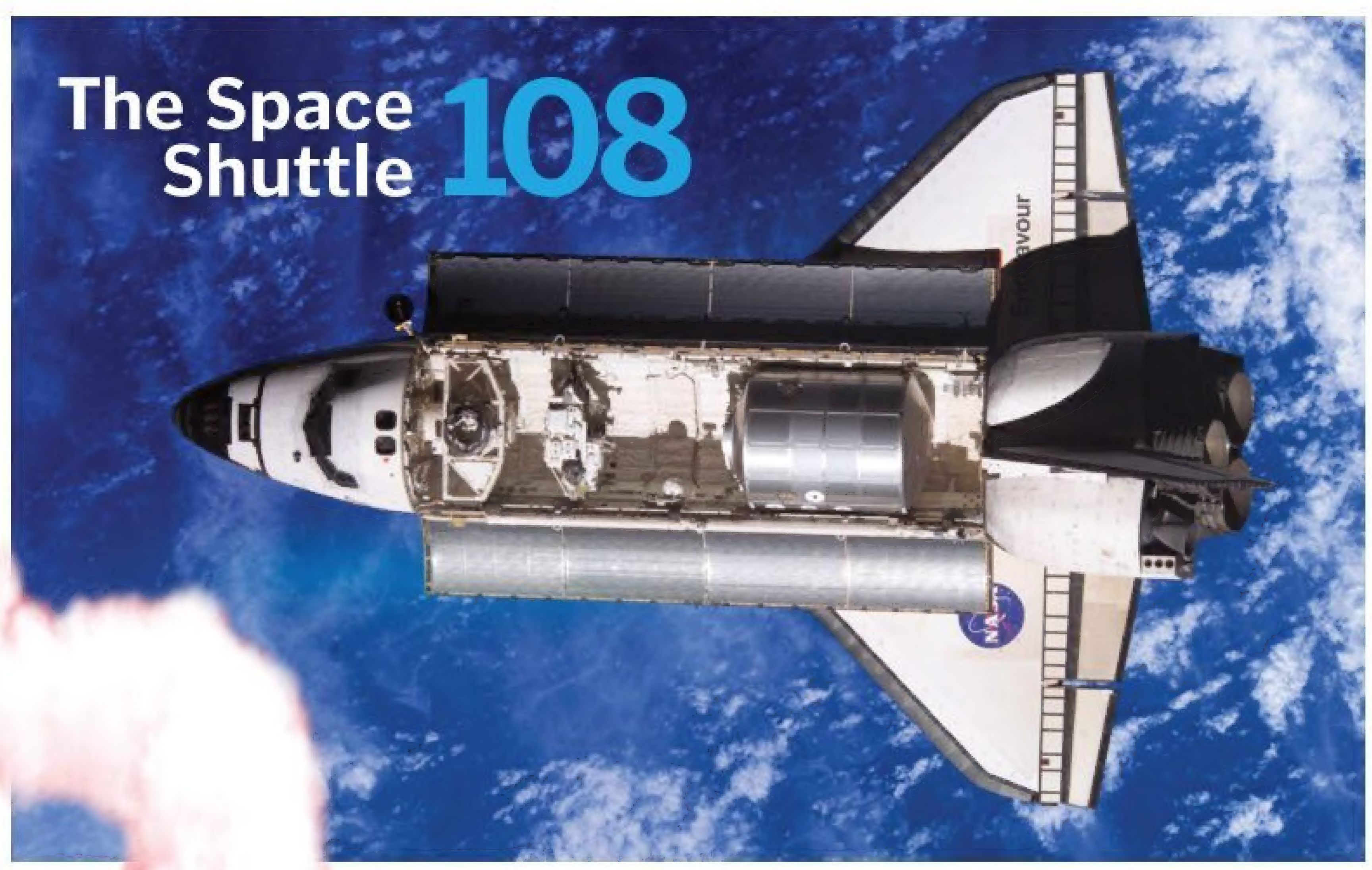

098 5 times the speed of sound

082
The largest passenger jet

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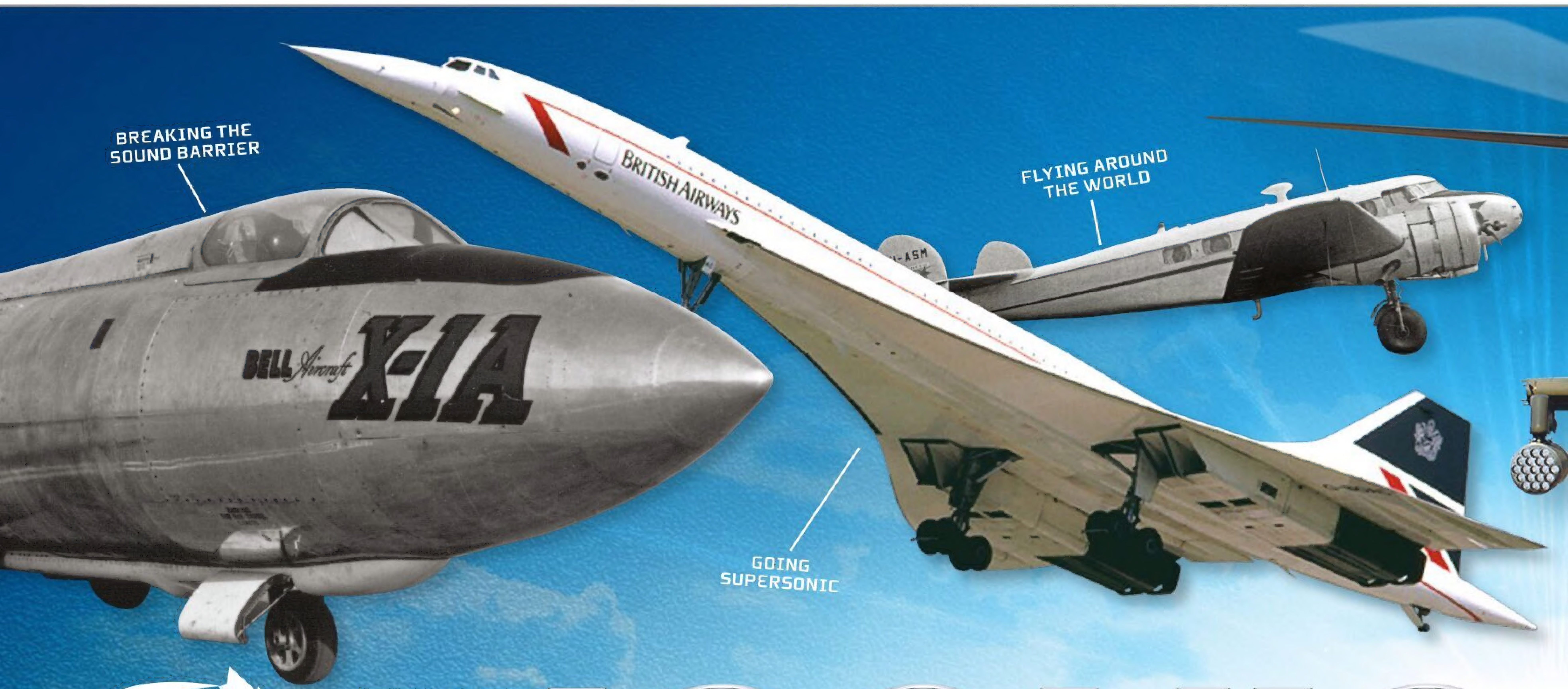
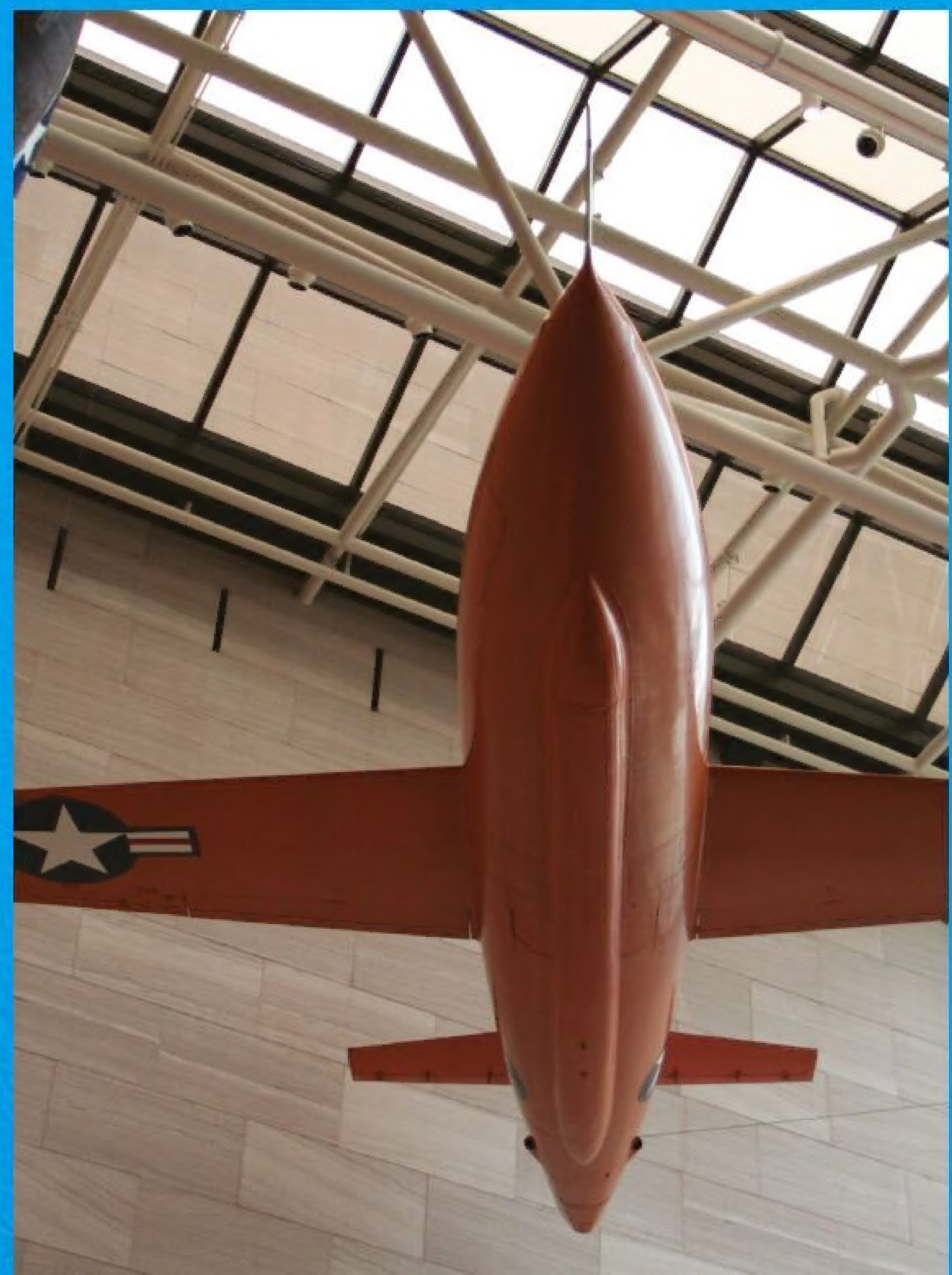


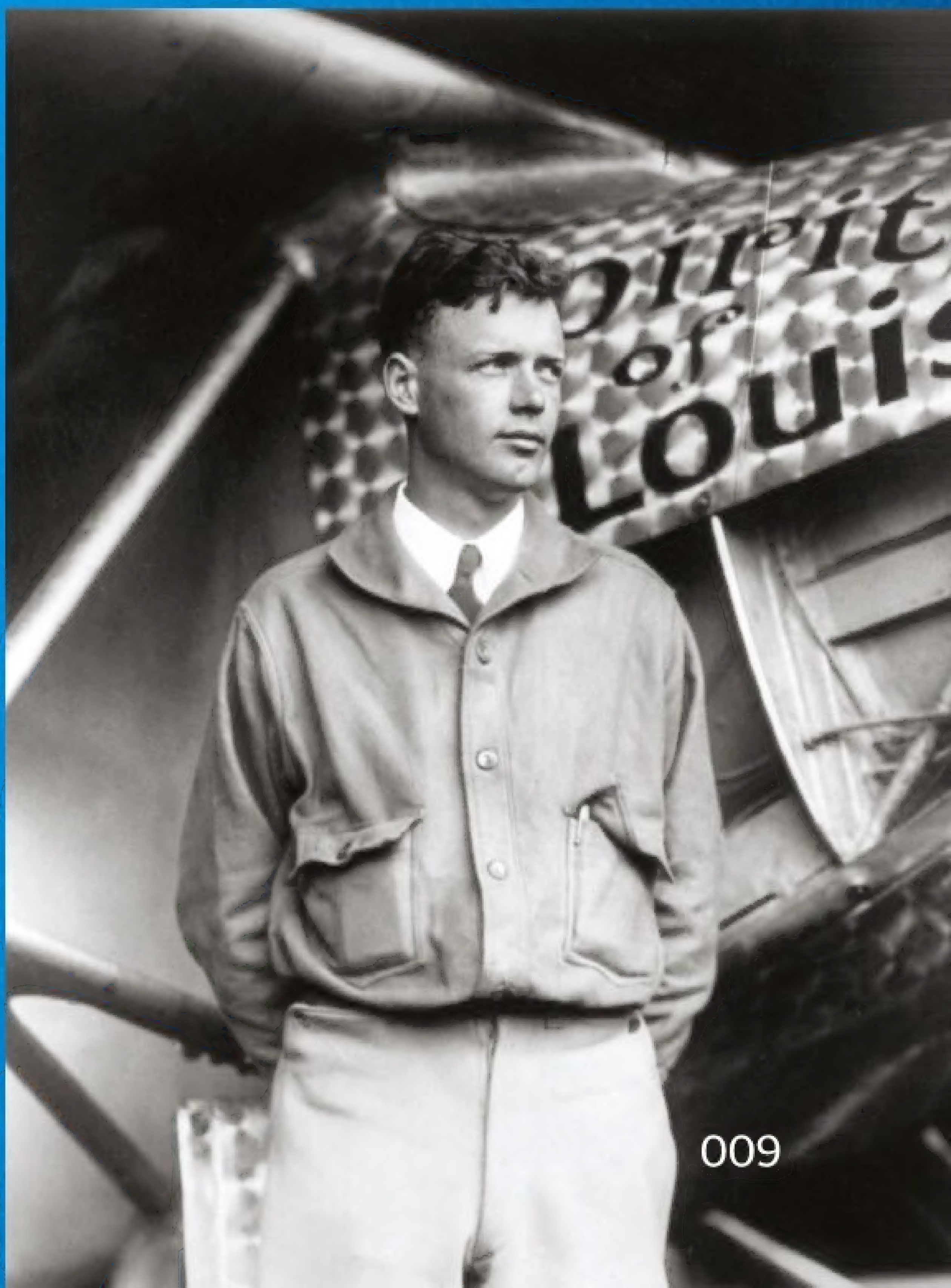
THE WORLD'S MOST ICONIC

From the early days of aviation all the way through to the modern



AIRCRAFT

day, iconic aircraft of all shapes and sizes have taken to the skies



Wright Flyer

The iconic aircraft that was created by the most famous of sibling partnerships

Orville and Wilbur Wright were dedicated to their task of developing powered flight. Meticulously tested, the Wright Flyer was constructed in Dayton, Ohio but failed to take off on the first tests carried out on 14 December 1903. It eventually managed to get airborne a few days later on 17 December and achieved a best of 260 metres (852 feet) as Wilbur and Orville took turns to pilot their invention. The aircraft was launched from a short monorail track by two modified bicycle wheel hubs. The engine was very basic and worked using a hand lever that could only open and close the fuel line rather than throttle. Prior to the Flyer, the brothers created various gliders from 1900 to 1903 that were tested without great success. Eventually, they found the perfect formula as it became the first heavier than air machine to get airborne. Designed in a biplane structure, the Wright Flyer had an unfortunate untimely demise when it was wrecked four days after its maiden flight by a huge gust of wind. The design was first housed in the British Science Museum before moving to the Smithsonian National Air and Space Museum in the USA after Orville's death in 1948.

The statistics...

Wright Flyer

Launch date: 17 December 1903

Length: 6.4m (21.1ft)

Weight: 274.4kg (605lb)

Wingspan: 12.2m (40.3ft)

Max speed: Minimal

Max altitude: Minimal

DID YOU KNOW? *The 747 was created by a team of 50,000 people including mechanics, engineers and secretaries*

Boeing 747

A behemoth of the skies, the size and sheer scale of the 747 is now legendary

In the 1960s, aviation companies had a problem. With the popularity of aviation soaring for business, recreation and industry, the supply of aircraft was struggling to meet demand. But Boeing had a solution up its sleeve; the biggest civilian airplane ever built, the 747. Built in less than 16 months by a group of workers known as 'the Incredibles', the design came in three variations – passenger, cargo and passenger/freighter – and was first flown in 1968. By 1970, this new breed of jumbo jet had fitted seamlessly into the world's air traffic and silenced critics. Since its inception, the 747s have appeared in a variety of models. The 747-400 was first flown in 1988 and is a combination of the earlier freight and passenger models. It is the bestselling model.

Statistics calculated in 2005 reveal that 1,365 747s have been delivered internationally to over 80 different customers. Incredibly, it has flown over 3.5 billion passengers. In recent years, new jumbo jets such as the Airbus A380 may have beaten the 747's size, but it remains an icon of the skies and proof for the first time that gigantic airliners were possible.

The statistics...

Boeing 747-400

Launch date: 1988

Length: 70.9 metres (231 feet)

Weight: 180,985kg (399lb)

Wingspan: 64.4m (211.5ft)

Max speed: 988km/h (614mph)

Max range: 13,449km (8,357mi)

Years in service: 1988-present

Stealth Bomber

Virtually invisible to radar, the Stealth Bomber is a scientific vision turned reality

Commonly known as the Stealth Bomber, the Northrop Grumman B-2 Spirit is a ground-breaking piece of aviation. The design was a giant leap forward in aviation technology and was first flown on 17 July 1989 before joining the US Air Force's operational fleet in 1993. Four 19,000 pound thrust F118-GE engines allow the B-2 to cruise at high subsonic speeds and was, at its peak, the largest military programme at Boeing with 10,000 people employed on the project. The engine is so state of the art that it uses a temperature control system to minimise the aircraft's thermal signature. A strategic, long-range heavy bomber, it only achieved full operational capacity in 2003, ten years after its introduction into the fleet. Twenty-one B-2s are now in operation and are located at the Whiteman Air Force Base in Missouri but are often transported around by a portable hangar system. The most frightening attribute of the B-2 is its capacity to carry an immense payload. Its armament includes many types of nuclear weaponry, Mark 84 bombs, cruise missiles and a rotary rocket launcher to name but a few. A key member of the USA's long range strike arsenal, it can fly in any weather condition and is a force to be reckoned with, especially as it is being constantly updated and improved by the US Air Force.

The statistics...

Northrop Grumman B-2 Spirit

Launch date: 1997
Length: 21.03m (69ft)
Weight: 71,700kg (158,071lb)
Wingspan: 52.43m (172ft)
Max speed: 1,010km/h (628mph)
Max altitude: 15,200m (49,869ft)

"The most frightening attribute of the B-2 is its capacity to carry an immense payload"

Concorde

The world's only ever-supersonic passenger aircraft is an incredible example of aviation engineering and technology

In 1971 the skies of Britain were dominated by the sound of sonic booms. These were the results of a futuristic Anglo-French project known as Concorde. After 5,000 hours worth of testing (making it the most tested aircraft of all time), it was ready. Seating 100 people, Concorde represented the next step in commercial travel. It was so fast that it still holds the record for the shortest transatlantic crossing, a scintillating 2 hours 52 minutes and 59 seconds. The aircraft accomplished this by utilising 'reheat' technology, which injects extra fuel at takeoff. This innovative technology helped the Concorde fly around the globe in 1992, on the 500th anniversary of Christopher Columbus' journey. It managed to complete the journey in just under 33 hours.

The Concorde's final flight was on 24 October 2003, when it was discontinued after a series of faults that ended in disaster in 2000 when it crashed, killing 113 people. The Concorde made a total of 50,000 flights for 2.5 million passengers and despite its retirement, is still held in high regard as an icon of aviation and there are still calls to bring it back the world's only ever supersonic passenger airline back into service.

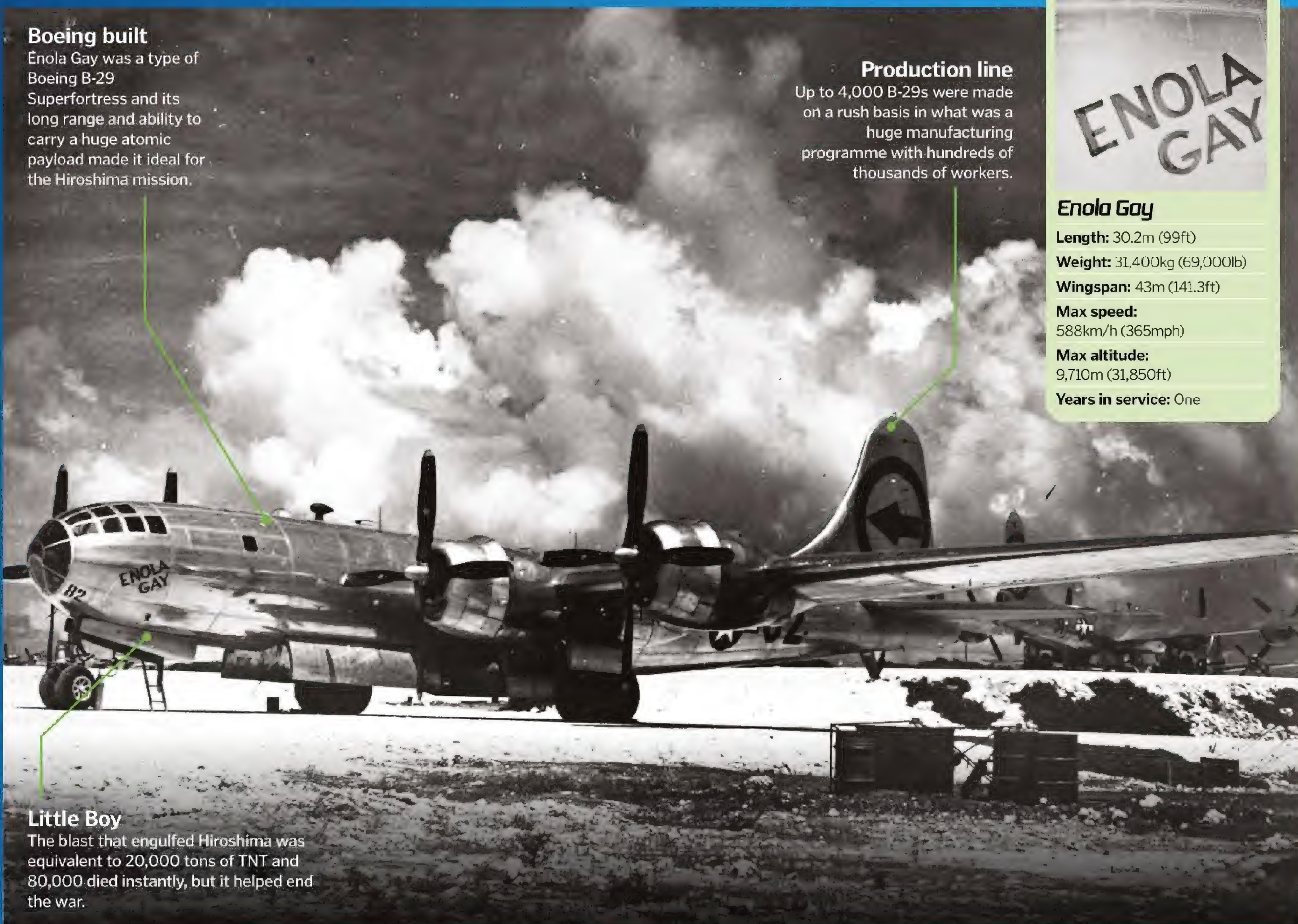
The statistics...

Concorde

Launch date: 1976
Length: 62.1m (203ft)
Weight: 10.6 tons (23,400lb)
Wingspan: 25.5m (83.8ft)
Max speed: 2,172km/h (1,349mph)
Max altitude: 18,288m (60,000ft)
Years in service: 27

The Enola Gay

A plane entirely famous for its atomic payload, the Enola Gay dropped one of the most destructive bombs in human history



The statistics...

Enola Gay

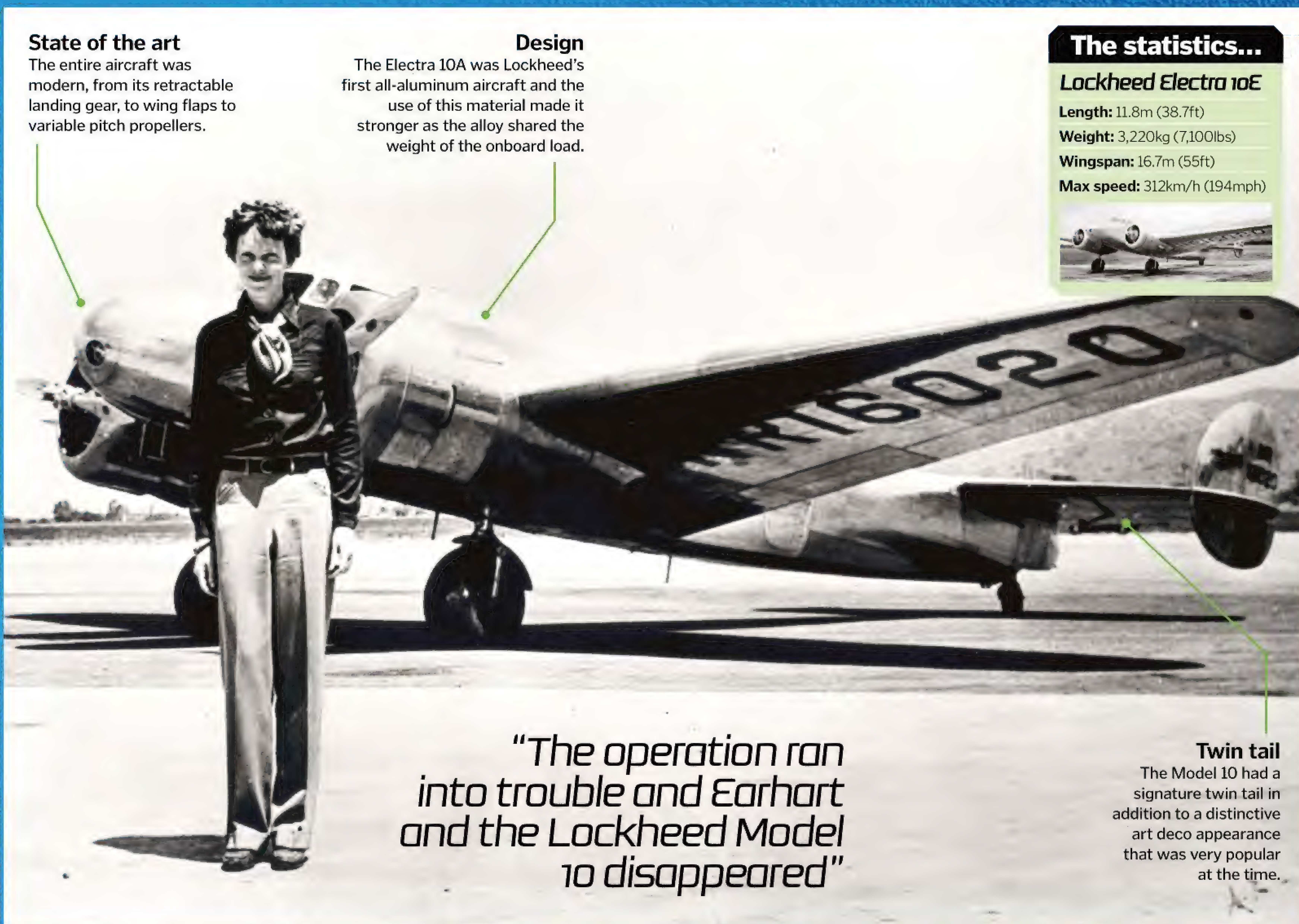
Length: 30.2m (99ft)
Weight: 31,400kg (69,000lb)
Wingspan: 43m (141.3ft)
Max speed: 588km/h (365mph)
Max altitude: 9,710m (31,850ft)
Years in service: One

'Enola Gay;' and 'Little Boy'. Two names that are now synonymous with changing the city of Hiroshima and the whole world forever. Named after pilot Paul W. Tibbets' mother, Enola Gay was a B-29 bomber built under the top-secret 'Silverplate' programme. Part of a batch of 15 bombers, it was chosen to fly the first ever atomic combat mission. The weapon would be known as 'Little Boy' and was a 15-kiloton bomb. Taking off at 2.45am local time, it arrived in Iwo Jima at 6.05am and armed its payload. After Little Boy was dropped 11.5 miles from the detonation point, the aircraft turned to make its hasty escape. As the atomic bomb sent Hiroshima to oblivion, Enola Gay was rocked by several after shocks as it withdrew. The crew remember seeing the resulting mushroom cloud for an hour and half afterwards as the aircraft returned to base, mission accomplished. Unknown to many, Enola Gay actually went on a second mission later the same month to scout out the target for the second atomic bombing mission. Today it is housed in the US National Air and Space Museum but will always be remembered for that devastating day in the summer of 1945.

DID YOU KNOW? *Amelia Earhart was only the 16th woman in the world to be issued a pilot's license*

Lockheed M10 Electra

Often overshadowed by its infamous pilot, the Lockheed Model 10 was still an iconic aircraft



State of the art
The entire aircraft was modern, from its retractable landing gear, to wing flaps to variable pitch propellers.

Design
The Electra 10A was Lockheed's first all-aluminum aircraft and the use of this material made it stronger as the alloy shared the weight of the onboard load.

Twin tail
The Model 10 had a signature twin tail in addition to a distinctive art deco appearance that was very popular at the time.

The statistics...

Lockheed Electra 10E

Length: 11.8m (38.7ft)
Weight: 3,220kg (7,100lbs)
Wingspan: 16.7m (55ft)
Max speed: 312km/h (194mph)

"The operation ran into trouble and Earhart and the Lockheed Model 10 disappeared"

Built as a response to the Douglas DC-2 and the Boeing 247, Lockheed was one of the companies transforming commercial aviation in interwar USA. Twin engine, the plane was originally intended for commercial use and could accommodate ten passengers and two crew. Before being used by Earhart, Northwest Airlines flew the plane in its fleet in the late 1930s and it was also taken on by European and Australian firms. The aircraft's most famous moment however, was undoubtedly its final journey. The plane used on the voyage was actually a modified version of the original model. More fuel tanks were added to the aircraft, increasing the carrying capacity and also the electronics were altered to add radio direction finders, which was state of the art at the time. Piloted by young pilot Amelia Earhart, the mission was simple; fly around the world. Tragically, the operation ran into trouble and Earhart and the Lockheed Model 10 disappeared in mysterious circumstances in October 1937. The reasons are still debated to why Earhart and her navigator Fred Noonan disappeared on the final leg of their journey with reasons ranging from a lack of fuel to a crash landing.

LZ 129 Hindenburg

This colossal machine is an example of a bygone era of aviation

The statistics...

LZ 129 Hindenburg

Launch date: 4 March 1936
Length: 245m (803.8ft)
Diameter: 41.2m (135.1ft)
Max speed: 135km/h (84mph)
Crew: 40 flight officers, 12 stewards and cooks
Years in service: One year and two months

In the first few decades of the 20th century, giant airships filled the sky. They were the preferred transport of the rich and famous and were particularly popular in Germany, where Zeppelin airships were all the rage. The Hindenburg was constructed solely for transcontinental transportation and after its maiden flight, became the largest object ever to fly at a mammoth 2.1 million cubic metres (7 million cubic feet). The airship finally got airborne after financial support by the Nazi Government and its maiden flight to the USA occurred on 31 March 1936. By the end of the year it had crossed the Atlantic 34 times carrying both passengers and cargo. It even had an autopilot system that could keep the ship on course in stable weather conditions. All seemed to be going well for the new technology but disaster would strike on 6 May 1937. When flying over Lakehurst, New Jersey an electrostatic discharge ignited with leaking hydrogen, causing the Hindenburg to explode dramatically. Miraculously, only 35 of the 97 passenger crew died with the majority just escaping with their lives. The disaster sent shockwaves across the world and the zeppelin industry never recovered. The age of transatlantic airship travel was over before it really began.

Fokker Dr.I

The most famous German aircraft of the Great War and the triplane of choice for the Red Baron

The statistics...

Fokker Dr.I

Launch date: 1917
Length: 5.77m (18.93ft)
Weight: 406kg (895lb)
Wingspan: 7.20m (23.62ft)
Max speed: 165km/h (103mph)
Max altitude: 6,095 m (19,997ft)
Number produced: 320

"The fighter remains an evocative symbol of the dogfights over the Western Front"

Remembered as one of the greatest aircraft of the First World War, the Fokker DR.I filled British and French hearts with dread. Powerful and highly manoeuvrable, opposing pilots quickly learnt that it was not be taken lightly, especially when it was being piloted by Manfred von Richthofen, the German fighter ace nicknamed 'the Red Baron'. As the war progressed, the triplane was hampered by structural issues and only 320 were produced. It could only last for a total of 80 minutes in the air on one tank of fuel and they were grounded completely for a period in the winter of 1917 when the wing attachment points were considered far too weak when in flight. Part of the Jagdgeschwader 1 fighter unit, the Dr.I returned to the skies in the spring of 1918 but was only ever truly effective in the hands of skilled pilots, so never made it as the main aircraft in the German air force, the Luftstreitkräfte. However, the fighter remains an evocative symbol of the dogfights over the Western Front and the bright red edition piloted by the formidable Red Baron.

Apache Helicopter

Destructive on land, sea and air, the Apache isn't far off being the ultimate military machine

A nightmare for tanks and ground troops alike, the Apache has revolutionised modern warfare. An immensely powerful war machine, the Apache is feared across the globe and can spring into action at any time, day or night, rain or shine. The AH-64 is a stalwart of the US and British militaries and has been used with great success in Iraq, Afghanistan and Kosovo. The Gulf War in particular saw the Apache come into its own, with the Iraqi tanks no match for a combined AH-64 and F-117 Nighthawk stealth fighter assault. The gunship is effective on land, sea and air and is able to quickly respond to any skirmish, making it an ideal rapid response unit that can lead counterattacks. The design has proved so popular that it has been developed and improved on in various other models that can be used in almost any terrain. It has also caught the attention of a number of other militaries around the world with Israel, Greece, Japan and the Netherlands all incorporating Apaches into their ranks. Boeing (known as MacDonnell Douglas at the time of the first Apache) was given a £158 ($247) million contract in 2010 to build even more of these beasts for use in global peacekeeping.

The statistics...

Boeing AH-64 Apache

Launch date: 1984
Length: 17.73m (58.17ft)
Weight: 6,838kg (15,075lb)
Max speed: 279km/h (173mph)
Years in service: 30

Cockpit
Two pilots control the war machine, which has a state-of-the-art cockpit complete with long-range communication and navigation systems.

Engine
Requiring expert manoeuvrability to dodge enemy fire and take down insurgents, the Apache has that in abundance thanks to its T700 Turboshaft engine.

Weaponry
The Apache's awesome arsenal packs a punch and is made up of Hellfire laser-designated missiles, a M230 chain gun and hydra rockets.

Bell X-1

The first plane to go supersonic, the Bell X-1 smashed the sound barrier in 1947

Rocket launch
To enable the Bell to reach its target speed and for safety reasons, the aircraft was only ever air launched from Boeing B-29 or B-50.

"The design was so good that the X-1 provided inspiration for the space programme"

Material
The X-1 was built with high strength aluminium and radium paint in an international orange paint scheme.

Need for speed
Cabin pressurisation, retractable landing gear and 12 nitrogen fuel spheres gave the X-1 the best chance of achieving its goal.

US Air Force pilot, Captain Charles E Yeager, broke the speed of sound on the 14 October 1947 in this very aircraft. Attaining a speed of 1,127 kilometres (700 miles) per hour or Mach 1.06, the plane, nicknamed Glamorous Glennis after the pilot's wife, entered the record books. The X-1 wasn't launched in the orthodox way and was instead propelled via air-launch from the bomb bay of a Boeing B-29. The record attempt wasn't the last of the X-1's record breakers, though. On 26 March 1948, it reached the highest velocity and altitude of a manned airplane up to that time. A single engine, single seat aircraft, 'Glennis', broke all idea of a sound barrier using a liquid fuelled 6,000-pound thrust rocket engine. The aircraft was one of a kind, shaped like a .50-caliber bullet – a round that was stable in supersonic flight when fired from a gun. The design was so good that the X-1 programme helped provide the inspiration for the space programme that would begin in subsequent decades. One of the most important aircraft of all time, the Bell X-1 ushered in a new era; the supersonic age.

The statistics...

Bell X-1

Launch date: 1946
Length: 9.45m (31ft)
Weight: 3,674kg (8,100lb)
Wingspan: 8.54m (28ft)
Max speed: 1,540km/h (957mph)/ Mach 1.45
Max altitude: 21,900m (71,900ft)

Supermarine Spitfire

The heroic British fighter of World War II that took the fight in the skies back to the German Luftwaffe

One of the most enduring images of the Second World War, the Spitfire is credited with saving the British Isles from the threat of German invasion. Fast, manoeuvrable and with an iconic engine sound, the Spitfire combined well with the Hawker Hurricane against the threat of the Messerschmitts. The Battle of Britain wasn't the Spitfire's only major contribution. It served the Allies with distinction over the course of the war, becoming the most widely produced British fighter of the war. It was constantly upgraded to battle the best the Luftwaffe had to offer and fought in every theatre of the war. D-Day and the invasion of Sicily wouldn't have happened if it wasn't for the excellent air support the Spitfire's provided. A Seafire version was created specifically for use in the Royal Navy on aircraft carriers and they became invaluable in the battle in the Pacific against Japan. Quintessentially British, the Spitfire was sold to various air forces around the world after the war but remains an icon of plucky British resistance in the summer of 1940. It is estimated that over 20,000 Spitfires were made and around 50 are still flying today as its legendary status lives on.

The statistics...

Supermarine Spitfire

Launch date: 1936

Length: 9.12m (29.11ft)

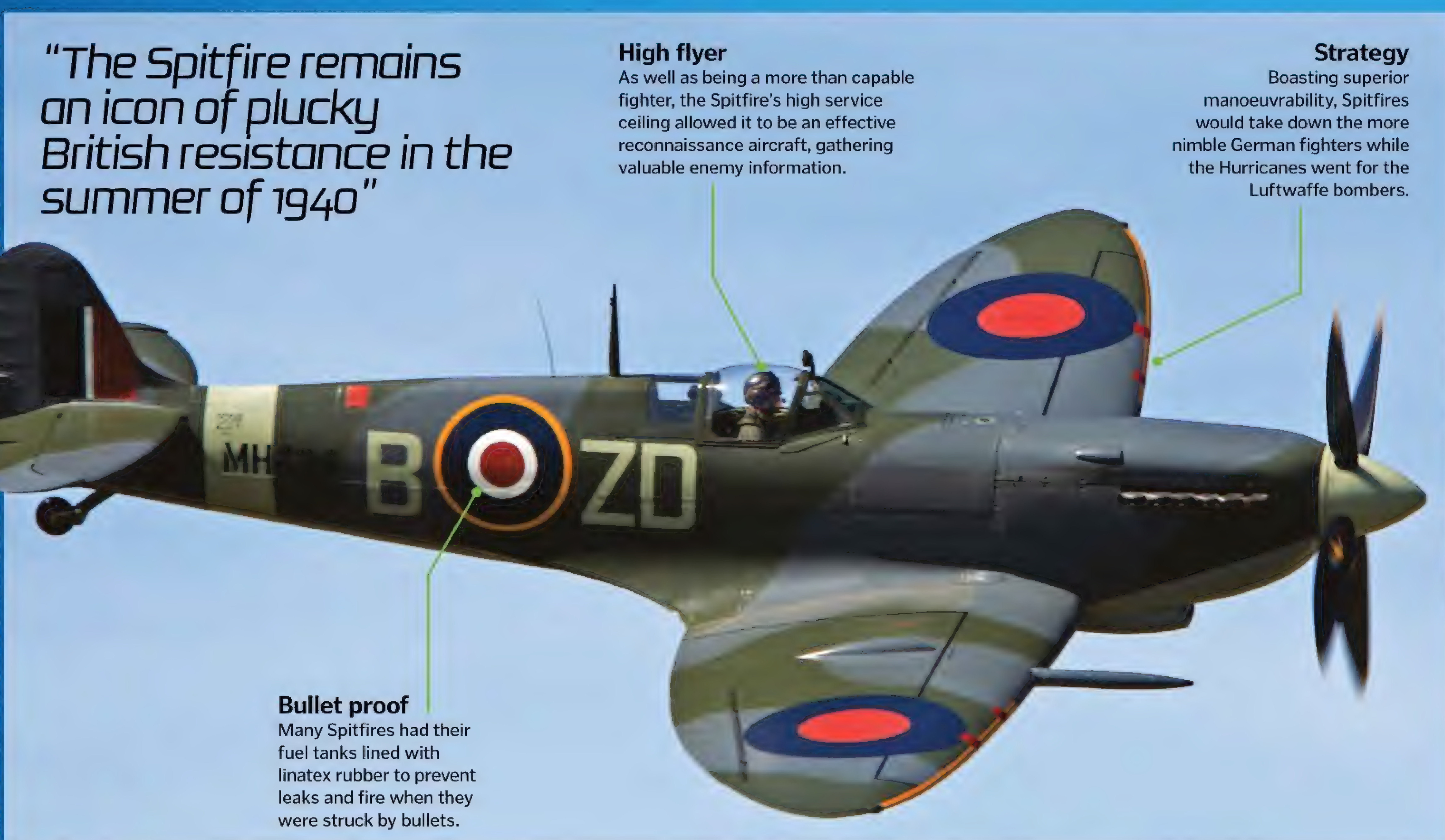
Weight: 2,257kg (4,976lb)

Wingspan: 11.23m (36.10ft)

Max speed: 584km/h (362mph)

Max altitude: 10,668m (35,00ft)

Years in service: 19



DID YOU KNOW? *The first aircraft to make a solo transatlantic flight, the St Louis stayed in the air for 33.5 hours!*

Spirit of St Louis

With a prize of $25,000, US pilot Charles Lindbergh jumped at the chance to pilot the famous monoplane

The statistics...

Spirit of St Louis

Launch date: 1927
Length: 8.41m (27.7ft)
Weight: 2,330kg (5,135lb)
Wingspan: 14.02m (46ft)
Max speed: 200km (120 miles)

After the Wright Brothers and their contemporaries had made flight achievable, aviators competed to take aviation to an even higher level. Charles A. Lindbergh was one of these men and in May 1927 competed for $25,000 to be the first to cross the Atlantic non-stop. French hotel owner Raymond Orteig had a great passion for flying and offered the best pilots in the world the cash prize. Lindbergh and the Spirit of St Louis were the ideal team to undertake the task. The plane had been specifically constructed for the mission and in test flights it managed to break the transcontinental record by flying from San Diego to New York in 21 hours and 40 minutes. Any item that wasn't needed was removed so Lindbergh was forced to fly with no radio, parachute or navigation lights! The historic journey was made between 20-21 May and the Spirit of St Louis was in such good shape, it was constantly flown around the Americas for years by Lindbergh to increase interest in aeronautics. The plane is now at the Smithsonian National Air and Space Museum in Washington DC, forever an icon.

HOW IT WORKS BOOK OF AIRCRAFT

Military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F-35 AND THE FUTURE FIGHTERS

Legacy aircraft worldwide are being blown out of the skies by a formation of revolutionary multi-role fighter jets, offering all-round air supremacy and a lethal barrage of explosive new technology

5 TOP FACTS
F-35 Lightning II

Birth
1 The F-35 was born out of the joint strike fighter (JSF) programme, which was initiated to create an aircraft that would replace the F-16, A-10, F/A-18 and AV-8B tactical fighter jets.

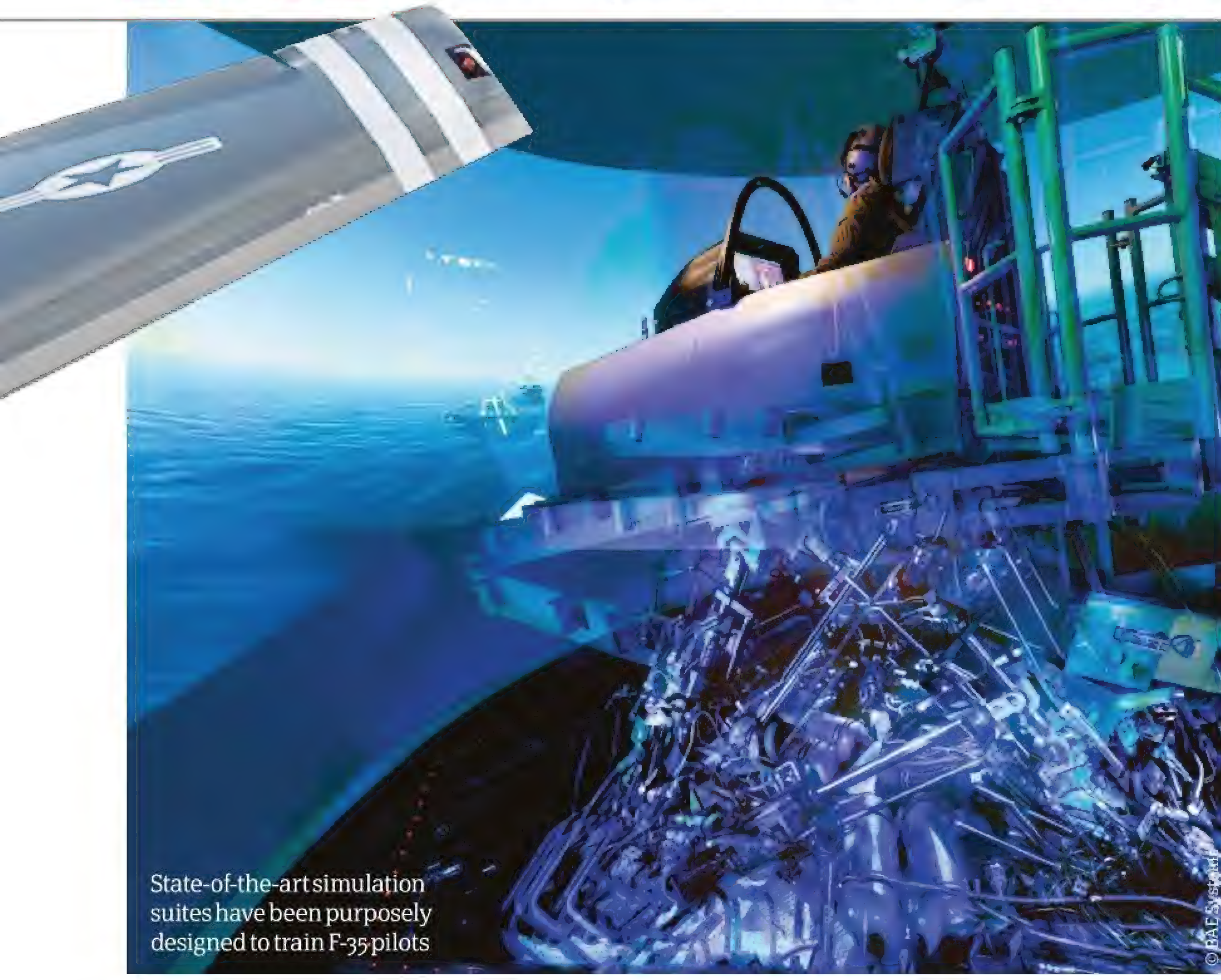
X-35
2 The prototype F-35 was the Lockheed Martin X-35, which narrowly beat a rival design from Boeing (X-32), despite both aircraft exceeding or meeting the JSF requirements.

DoD
3 Interestingly, the F-35 designation of the Lightning II is out of sequence with standard DoD numbering. It was supposed to be named the F-24 instead.

Alliance
4 There are eight global partners in the F-35's development along with the USA: the UK, Italy, the Netherlands, Australia, Canada, Denmark, Norway and Turkey.

LiftSystem
5 The STOVL variant of the F-35 Lightning II uses the Rolls-Royce LiftSystem, an innovative propulsion system that allows for the main engine exhaust to be redirected for vertical lift.

DID YOU KNOW? Total development costs of the F-35 Lightning II are estimated to have run to $40 billion


State-of-the-art simulation suites have been purposely designed to train F-35 pilots

© BAE Systems

"Each F-35 utilises structural nanocomposites, such as carbon nanotube-reinforced epoxy and bismaleimide"


An F-35 on Lockheed Martin's primary build line at Fort Worth in Texas

© BAE Systems

F-35 Lightning II

Put simply, the most versatile, deadly and technologically advanced fighter jet in the world

The latest and greatest 'black project' from Lockheed Martin's Skunk Works – technically referred to as the Advanced Development Programs (ADP) unit, a classified division of the company unrestrained by bureaucracy – the F-35 Lightning II is the most advanced fighter jet on Earth. It's the first and only stealthed, supersonic, multi-role fighter.

Born out of a demand to dominate the fluid 21st-century battlefield, replacing a plethora of legacy aircraft such as the F-16 and A-10 Thunderbolt II, the F-35 is rewriting the rulebook on aircraft design, capable of performing almost any possible role imaginable today – be that strike, support or reconnaissance – with greater efficiency than any other aircraft made to date. The cost of this performance? £89m ($139m) per plane.

So what does all that cash actually buy you? To start, the most powerful powerplant ever fitted to a fighter aircraft. The F-35, across all its three variants – read: F-35A, F-35B and F-35C, differentiated largely by takeoff mechanism – is fitted with a Pratt & Whitney F135 afterburning turbofan jet engine, which delivers a mighty 19,500 kilograms (43,000 pounds) of thrust and grants a sound-shattering top speed of over 1,930 kilometres (1,200 miles) per hour; that's over Mach 1.6 or, to put it another way, infinitely faster than your gran's Mini Metro!

The cash, which is being dropped in large quantities by the States, as well as eight other global partners including the United Kingdom – which is set to deploy the aircraft on its new Queen Elizabeth-class aircraft carriers – also purchases the operator one of the most advanced aircraft structures in existence. Each F-35 utilises structural nanocomposites, such as carbon nanotube-reinforced epoxy and bismaleimide (BMI), to produce a framework unrivalled in lightness and strength, as well as heavily integrating epoxy glass resin to maximise aerodynamics. In terms of skin and coatings, each F-35 aircraft sports a radar cross-section the size of a golf ball thanks to the implementation of fibre-mat over the fuselage.

The cockpit is also state of the art, delivering a full-panel-width, panoramic glass cockpit display as well as a host of bleeding-edge avionics and sensors such as the Northrop Grumman AN/APG-81 AESA radar and electro-optical targeting system (EOTS). Further, much of the cockpit has been optimised for speech-recognition interaction, allowing the pilot to control many parts of the jet by voice alone.

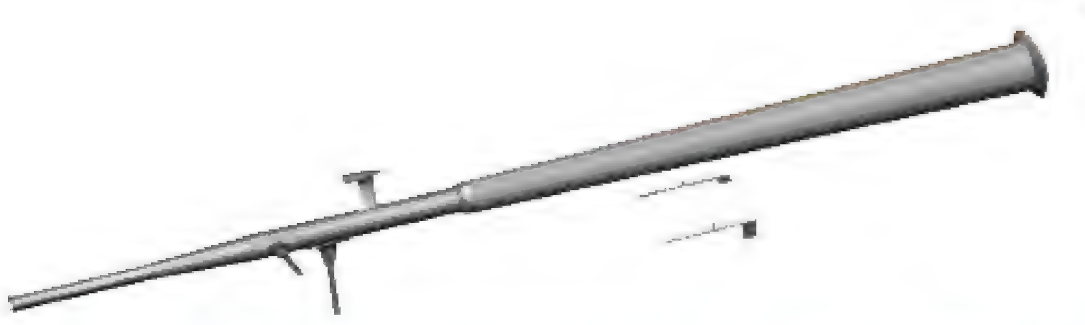
Of course, the main attraction of the Lightning II is its diverse armaments – the equipment that transforms it from technical marvel into a master of destruction. You want air-to-air prowess? You've got it, with the F-35 capable of launching AIM-120 AMRAAMs, AIM-9X Sidewinders, IRIS-Ts and the futuristic beyond-visual-range MBDA Meteor. For maximum air-to-ground penetration, take your pick from AGM-154 JSOWs, SOM Cruise Missiles and Brimstone anti-tank warheads. Even if you want to engage marine-based targets the F-35 delivers the goods, capable of launching the new anti-ship Joint Strike Missile (JSM). Throw in a raft of other munitions, including the Mark 80 series of free-fall bombs, an Mk.20 Rockeye II cluster bomb, the Paveway series of laser-guided bombs and even, in DEFCON 1 situations, the B-61 nuclear bomb and you have one extremely versatile, powerful and deadly feat of aviation.

The rate of climb of the F-35 is currently classified

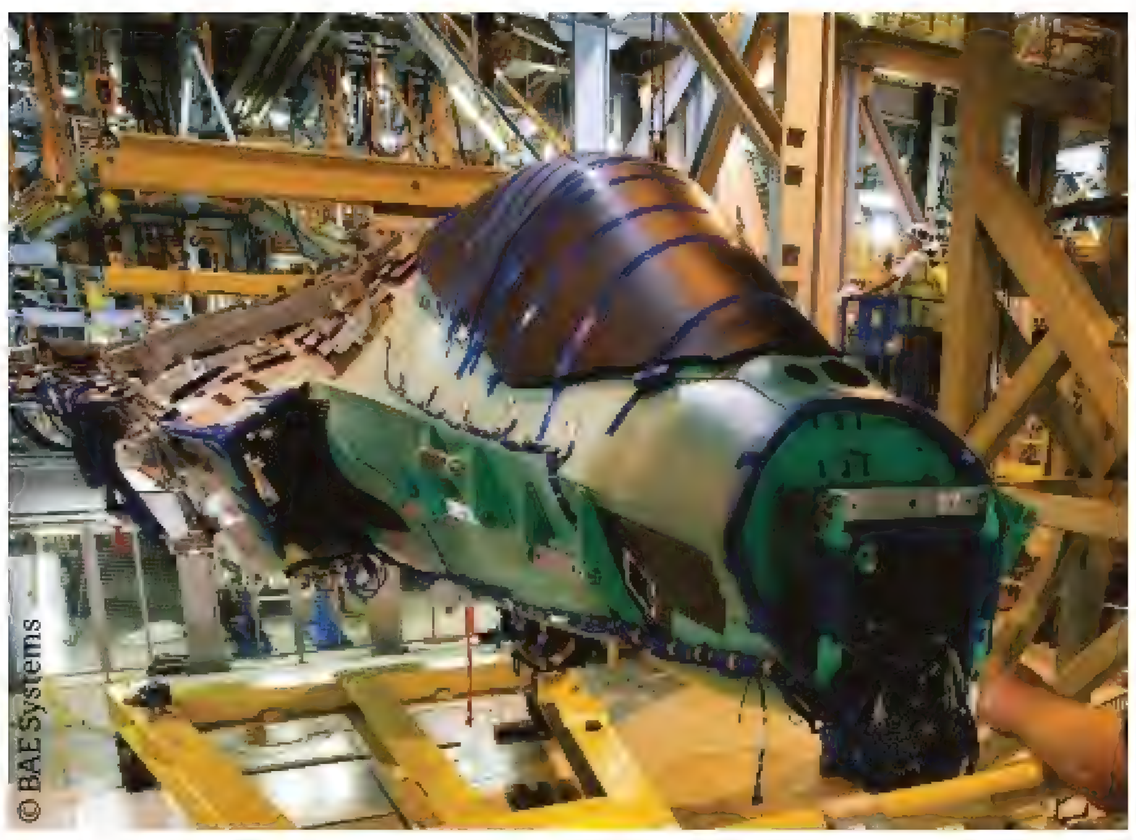
© BAE Systems

Anatomy of the F-35 Lightning II

How It Works breaks down this awesome piece of military engineering to see what makes it so advanced



LiftSystem
Made by tech-masters Rolls-Royce, the F-35's LiftSystem is an innovative propulsion system that allows for the main engine exhaust to be redirected for direct vertical lift. Perfect for carrier deployment.



© BAE Systems

Cockpit
A panoramic glass cockpit display (PCD) is standard on the F-35, allowing unparalleled visibility. Speech-recognition systems also offer audio control of parts of the pilot interface.

© BAE Systems

Sensors
The main sensor installed in the F-35 is an AN/APG-81 AESA radar, which is produced by Northrop Grumman. This main radar is augmented with an electro-optical targeting system (EOTS) mounted under the nose.

Armament
Asides from a stock GAU-22/A quad-barrelled cannon, the F-35 can carry a wide variety of bombs and missiles, ranging from AIM-9X Sidewinders, through AGM-128s and on to JDAM-guided bombs.

History of multi-role fighter jets

The F-35 is the culmination of more than 30 years of development into producing a single, king-of-all-trades fighter plane

1979 Panavia Tornado

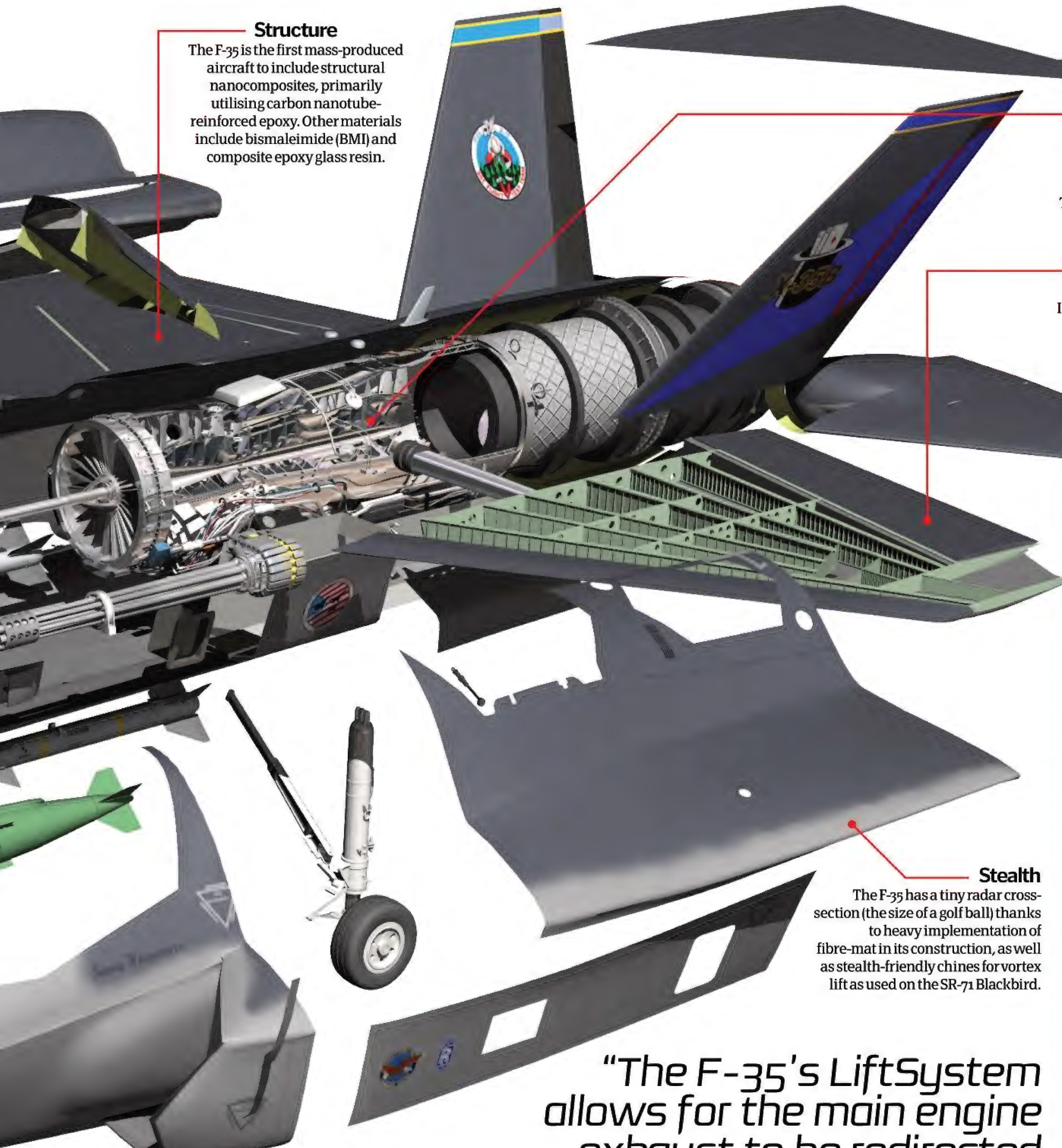
The first multi-role fighter to be produced, the Panavia Tornado – across its three variants (each providing differing abilities) – offered its owner the best of striker, bomber, interceptor and reconnaissance aircraft.

1983 McDonnell Douglas F/A-18 Hornet

Maybe the most recognisable multi-role fighter until the F-22, the Hornet was an all-weather, carrier-capable fighter specialising in short/medium-range bombing ops.

1988 JAS-39 Gripen

Another early delta-wing, multi-role fighter, the Gripen was designed to be incredibly lightweight for a fighter and sported impressive air-to-ground bombing capabilities. It has recently been upgraded for continued use.



Structure
The F-35 is the first mass-produced aircraft to include structural nanocomposites, primarily utilising carbon nanotube-reinforced epoxy. Other materials include bismaleimide (BMI) and composite epoxy glass resin.

Powerplant
A Pratt & Whitney F135 afterburning turbofan delivers 19,500kg (43,000lb) of thrust to the F-35, allowing a top speed of over 1,930km/h (1,200mph). The engine is the most powerful ever installed in a fighter aircraft.

Wings
The total wing area of the Lightning II varies dependent on configuration, with the CTOL and STOVL variants sporting $43m^2$ ($460ft^2$) and the CV variant $62m^2$ ($668ft^2$).

Stealth
The F-35 has a tiny radar cross-section (the size of a golf ball) thanks to heavy implementation of fibre-mat in its construction, as well as stealth-friendly chines for vortex lift as used on the SR-71 Blackbird.

> "The F-35's LiftSystem allows for the main engine exhaust to be redirected for direct vertical lift"

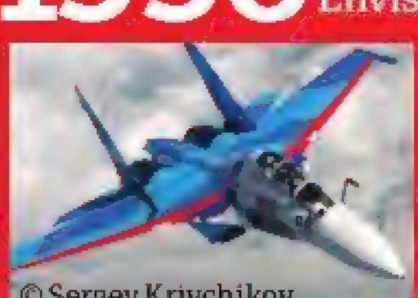
The statistics...

F-35A

Crew: 1
Length: 15.7m (51.4ft)
Wingspan: 10.7m (35ft)
Height: 4.3m (14.2ft)
Weight: 13,300kg (29,300lb)
Powerplant: 1 x Pratt & Whitney F135 afterburning turbofan
Dry thrust: 125kN (28,000lbf)
Thrust with afterburner: 191kN (43,000lbf)
Max speed: Mach 1.6 (1,930km/h; 1,200mph)
Max range: 2,220km (1,379mi)
Max altitude: 18,288m (60,000ft)
Thrust/weight: 0.87
g-limit: +9 g
Guns: 1 x General Dynamics GAU-22/A Equalizer 25mm four-barrelled Gatling cannon
Hardpoints: 6 x external pylons, 4 x internal pylons
Max payload: 8,100kg (18,000lb)
Armament: Air-to-air, air-to-ground, anti-ship

© MOD Czech Republic

1996 Sukhoi Su-30
Envisioned as a fighter jet with excellent air-to-surface deep interdiction prowess (the ability to strike hostile targets at extreme range from friendly forces), the Russian Su-30 typifies multi-role designs from the mid-Nineties.



© Sergey Krivchikov

2000 Dassault Rafale
Marketed by Dassault as an 'omnirole' jet, the Rafale was an agile delta-wing fighter, specialising in air supremacy. A collapse in a multi-nation agreement, however, led it to be used for other roles by France and India.

2005 Lockheed Martin F-22 Raptor
Originally conceived as an air superiority fighter, the F-22 evolved over time into a multi-role jet, capable of ground attack and electronic warfare roles thanks to its extremely low radar cross-section.

© Rob Shenk

© Alex Pang

"Typhoon pilots are now linked to their aircraft by 'electronic umbilical cords'"

According to government officials, the T-50 will have a low radar cross-section and have the ability to supercruise (perform sustained supersonic flight)

© Maxim Maksimov

As well as air-to-air roles, the Typhoon can adapt to air-to-ground operations, delivering GBU-16 Paveway II bombs

Sukhoi T-50

Russia's hottest jet project currently in development, the highly classified Sukhoi T-50 is a fifth-generation multi-role fighter designed to deliver awesome long-range strike capabilities

Arguably the main competitor to the F-35 Lightning II, the Russian-made Sukhoi T-50 is an extremely advanced, twin-engine, multi-role jet fighter that, aside from being a top-level black project (in other words, highly hush-hush), promises to deliver an insane top speed, range and payload.

Power, which is titanic – 267 kilonewtons (66,000 pounds-force) of thrust on afterburner – comes courtesy of two Saturn 117 turbofan jet engines. The thrust has been drastically increased since the previous AL-31 powerplant and this not only allows the T-50 to easily surpass Mach 2 (a top speed of 2,500 kilometres, or 1,500 miles, per hour) but also supercruise – continuously fly at supersonic speeds without engaging the afterburner.

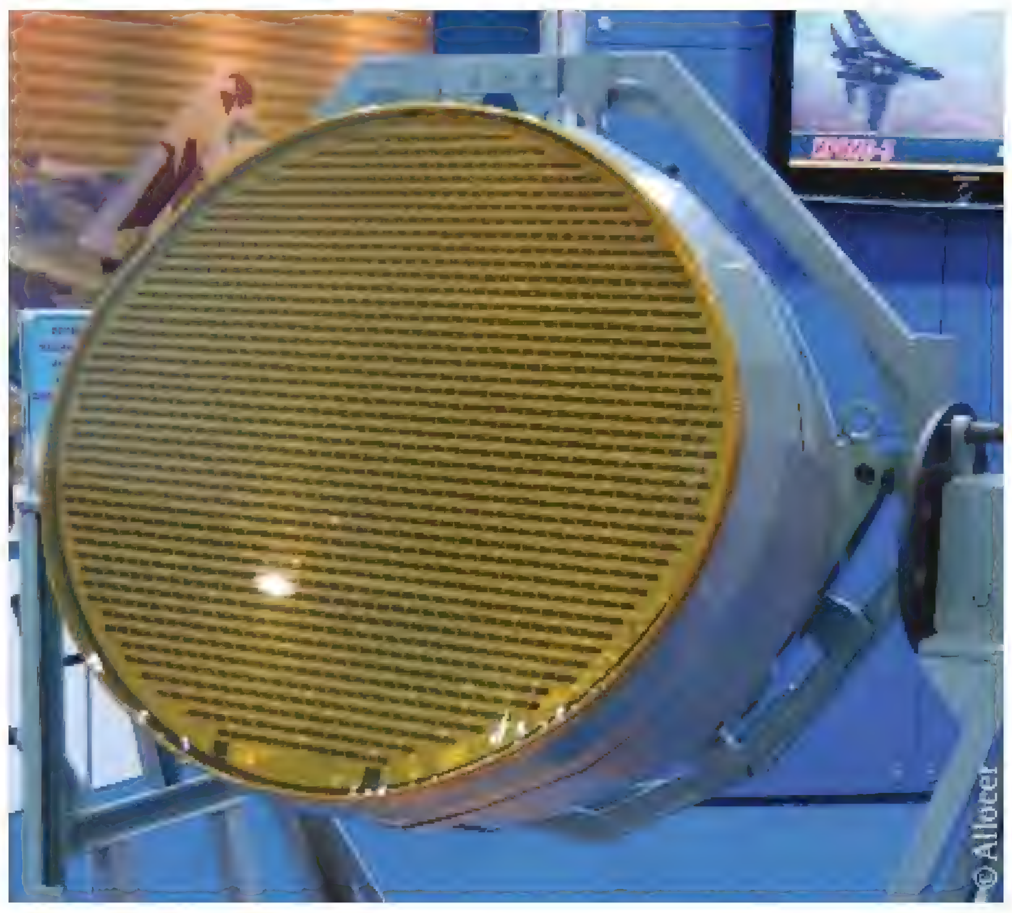
The reason for the twin-engine setup, as well as the supersized fuel tanks, is to help fulfil the T-50's design focus to specialise in long-range interdiction operations (striking at enemy targets that are located at a great range from allied forces). This is a core competency for modern Russian military bombing aircraft due to the size of the country and the great distances between stopover points.

Avionics are handled by an integrated radar complex, which includes three X-band active electronically scanned array (AESA) radars mounted to the front and sides of the aircraft, an infra-red search and track (IRST) system, as well as a pair of L-band radars on the wing leading edges, which are specially designed to detect very low observable (VLO) targets.

In terms of firepower, the production variant of the T-50 will boast up to two 30-millimetre cannons, as well as a mix of Izdeliye 810 extended-beyond-visual-range missiles, long-range missiles, K74 and K30 air-to-air short-range missiles and two air-to-ground missiles per weapons bay. Free-fall bombs can also be carried – with a limit of up to 1,500 kilograms (3,300 pounds) per bomb bay – as well as various anti-AWACS (airborne warning and control system) armaments, such as the RVV-BD variant of the Vympel R-37.

Currently only a handful of T-50s have been produced and flown, however it is expected that throughout its 35-year life span beginning in 2016, more than 1,000 jets will be made, each unit costing between £31-36m ($48-57m).

The NIIP AESA radar as will be used on the production variant of the T-50



© Allocer

The statistics...

© Dmitry Pichugin

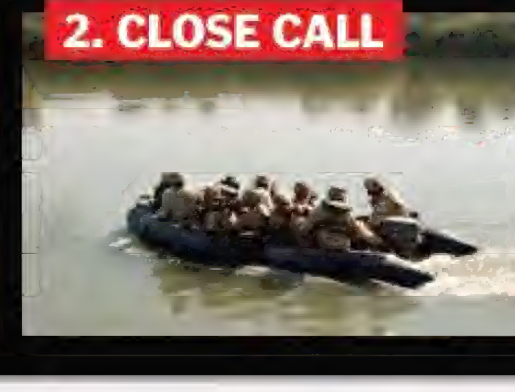
Sukhoi T-50

Crew: 1
Length: 19.8m (65.9ft)
Wingspan: 14m (46.6ft)
Height: 6.05m (19.8ft)
Weight: 18,500kg (40,785lb)
Powerplant: 2 x AL-41F1 afterburning turbofans
Max speed: Mach 2+ (2,500km/h; 1,560mph)
Max range: 5,500km (3,417mi)
Max altitude: 20,000m (65,600ft)
Rate of climb: Classified
Thrust/weight: 1.19
g-limit: Classified
Guns: 2 x 30mm cannons
Hardpoints: 6 x external pylons, 4 x internal pylons
Armament: Air-to-air, air-to-ground, anti-ship

1. ELECTRIC

Electronic warfare
Some jets use specialised equipment to control, disrupt or attack enemy targets with a host of cutting-edge electromagnetic weaponry.

2. CLOSE CALL



Close air support
Supporting ground troops with air action despite their close proximity. Achieved with fixed-wing or rotary aircraft.

3. LONG DISTANCE

Air interdiction
This role involves using aircraft to attack tactical ground targets that are not currently in close proximity to ground forces but located at a considerable range.

DID YOU KNOW? The Sukhoi T-50 is expected to be renamed to the Sukhoi PAK FA when it is officially launched in 2018

Eurofighter Typhoon

The Typhoon is one of the most adaptable multi-role fighters in operation today and has recently been upgraded to deliver enhanced air superiority and all-round lethality in its combat operations over the next decade

The Eurofighter Typhoon is currently one of the most agile aircraft in the world. It is so agile, in fact, that attempting to blow it out the skies is like trying to make a mile-long sniper shot in high wind. Why? It was built to be fundamentally aerodynamically unstable and, if it were not for its advanced fly-by-wire control system generating artificial stability, would be too much for even the most experienced pilot to handle. This instability, however, allows for pilots to perform some physics-bending manoeuvres at just plain stupid speeds – read: upwards of Mach 2 – delivering them a combative edge and helping to ensure total air supremacy.

Of course, agility alone can only take you so far – especially so when the hardware needs to fulfil almost every airborne military role imaginable. Good job then that the Typhoon can carry an abundance of weapons. You need to go toe-to-toe with enemy fighters in an air-to-air combat dogfight? No problem, take your pick from Sidewinder, ASRAAM and AMRAAM air-to-air missiles. Need to undertake a bombing run through hostile territory? Well, the Typhoon's 13 hardpoints allow for Maverick, HARM and Taurus munitions to be smartly delivered (via laser-guiding and GPS) with ice-cold efficiency. Need to disrupt a hostile target's comms network through a tactical electronic warfare strike… You get the point.

Supporting this awesome arsenal is an upgraded weapons system, which has been designed to unite the pilot and hardware like never before. Typhoon pilots are now linked to their aircraft by an 'electronic umbilical cord', which extends from a comms-optimised helmet directly into the jet's system. This not only allows images and videos of notable contextual information to be directly fed to the helmet's visor for immediate consultation by the pilot, but also enables special nodules on the helmet to be tracked by fixed sensors in the aircraft's cockpit. As such, wherever the pilot's head moves, the aeroplane knows exactly where they are looking and can automatically prep weapon stores dependent on the perceived level of threat.

Any future fighter though also needs to be prepared to defend itself against a barrage of smart munitions, which again – thanks to the Typhoon's perpetual evolution – the hardware delivers in spades. The entire jet is protected by a high-integrated defensive aids sub-system (DASS), also nicknamed Praetorian. Praetorian consists of a wide array of sensors and electronic/mechanical systems – detection is handled by both a radar warning receiver and laser warning receiver – that automatically track and then respond to both air-to-air and surface-to-air threats. The plane can respond by releasing chaff (eg small bits of aluminium or metallised glass, etc), flares and electronic countermeasures (ECM), as well as by releasing a towed radar decoy (TRD).

As of October 2011, 300 Typhoons are recorded to be in operation worldwide with over 170 aircraft on order.

"The Typhoon's 13 hardpoints allow multiple munitions to be smartly delivered with ice-cold efficiency"

The statistics…

Eurofighter Typhoon

Crew: 1
Length: 16m (52.4ft)
Wingspan: 11m (35.9ft)
Height: 5.3m (17.3ft)
Weight: 11,150kg (24,600lb)
Powerplant: 2 x Eurojet EJ200 afterburning turbofans
Dry thrust: 60kN (13,000lbf) each
Thrust with afterburner: 89kN (20,000lbf) each
Fuel capacity: 4,500kg (9,900lb) internal
Max speed: Mach 2+ (2,495km/h; 1,550mph)
Max range: 3,790km (2,350mi)
Max altitude: 19,810m (64,990ft)
Rate of climb: >315m/s (62,000ft/min)
Thrust/weight: 1.15
g-limit: +9/-3 g
Guns: 1 x 27mm Mauser BK-27 revolver cannon
Hardpoints: 13 (8 x under-wing, 5 x under-fuselage)
Max payload: 7,500kg (16,500lb)
Armament: Air-to-air, air-to-ground, anti-ship

A Typhoon undertakes a low pass at high speed

The RAF received its first multi-role capable Typhoons in March 2007

AEROBATIC DISPLAYS

THE AMAZING TECH BEHIND THE DEATH-DEFYING DISPLAYS

DID YOU KNOW? *The Red Arrows, whose motto is "Éclat" meaning brilliance, are based at RAF Scampton in Lincolnshire*

Anyone who's seen the Red Arrows or the Blue Angels perform will know why many consider these pilots to be the world's best. They execute death-defying stunts at breakneck speeds; flying low to the ground and experiencing g-forces that makes their heads feel like 20-kilogram (44-pound) balls. They manage not only to control their aircraft, but also to work perfectly in a team, pushing themselves and their aircraft to the limit.

The Blue Angels – the US Navy's flight demonstration squadron – and Red Arrows – the UK's Royal Air Force Aerobatic Team – have very interesting origins. After World War II ended, the US chief of naval operations, Admiral Chester Nimitz, was keen to maintain the high level of public interest in naval aviation. He feared that he would lose significant amounts of funding to other areas of the US Army; therefore, he devised a plan to create a flight exhibition team. Throughout the following decades, the Blue Angels flew a number of different planes, including the F6 Hellcat, the F-4 Phantom and the A-4 Skyhawk. They finally settled on the Boeing F/A-18 Hornet in 1986, the 40th anniversary of their conception, which they still use today. The Blue Angels now perform all over America, with air shows taking place between March and November.

The Red Arrows take their name from two aerobatic display teams that preceded them, the Red Pelicans and the Black Arrows. The first Red Arrow display team was formed in 1964 after concerns that aerobatic display pilots were neglecting their combat training, as they preferred to practice their stunts. The first official Red Arrows flew the Folland Gnat which had been used by the Yellowjacks in previous years. The original team flew with seven aircraft, until 1968 when they decided to adopt their now trademarked 'Diamond Nine' formation. In 1979, the BAE Systems Hawk – a modified version of the Royal Air Force's fast jet trainer – was chosen to replace the Gnat. The Red Arrows have now performed nearly 5,000 shows and celebrated their 50th season in 2014.

Death-defying displays

Find out how display pilots pull off their incredible manoeuvres with precision and coordination

Both the Red Arrows and the Blue Angels update their show routine each year, which typically lasts between 20 and 30 minutes. They prepare three different displays and choose which one to perform by examining the weather conditions. A 'full' or 'high' show will be performed in clear weather, when the cloud base is over 1,372 metres (4,500 feet) high. This allows a full, looping display to be carried out and means that even at the top of each loop, the planes will remain visible.

If the cloud base is lower than this and conditions are overcast, a 'rolling' or 'low' display is performed. When the weather is particularly bad and the cloud base is below 762 metres (2,500 feet), a 'flat' show is performed. This will include mainly flypasts and steep turns, as these are the only manoeuvres that remain visible in such poor conditions.

The first five Red Arrow planes (Reds 1 to 5) are the front part of the overall formation, known as 'Enid.' The remaining three planes, Reds 6 to 9, make up the rear section and are known as 'Gypo.' Reds 6 and 7 are the 'Synchro Pair,' and will perform opposition manoeuvres during the second half of the show. The Blue Angels also have a similar pair – the Blue 5 and 6.

Blue Angel 5 pilot Mark Tedrow spoke about the most challenging manoeuvre that he performs: "It's called the inverted tuck over roll which is where I'm trying to hide my plane behind Blue 6, so the crowd only see one aircraft. Last year we performed this upright, but this year we decided to make things harder and perform it inverted."

Being disciplined during a manoeuvre is vital for all display pilots. Hours of practice enable the Red Arrows to move nine aircraft as one. Red 2 pilot Mike Bowden, revealed how the Red Arrows achieve this visual feat: "There's a perfect position to be in during all manoeuvres and to achieve this we aim to triangulate a position on the Team Leader's aircraft," he explains. "We use two reference points to put us in the right part of the sky, which helps us to ensure that we don't get too close. Six feet [1.8 metres] apart is close enough when you've got nine aircraft in one vicinity."

Dye in the sky

Both the Blue Angels and the Red Arrows use smoke as a visual aid for spectators, enabling them to follow a traceable path from each plane during the display. The Red Arrows are famous for their white, red and blue smoke, while the Blue Angels stick to using just white smokes.

Adding small quantities of diesel into the jet exhaust pipe produces the vapour trails. As this diesel meets the high temperatures found in the exhaust it instantly vapourises, creating a strong, visible, white smoke. The Red Arrow pilots change the smoke's colour by adding dye through switches on their control column.

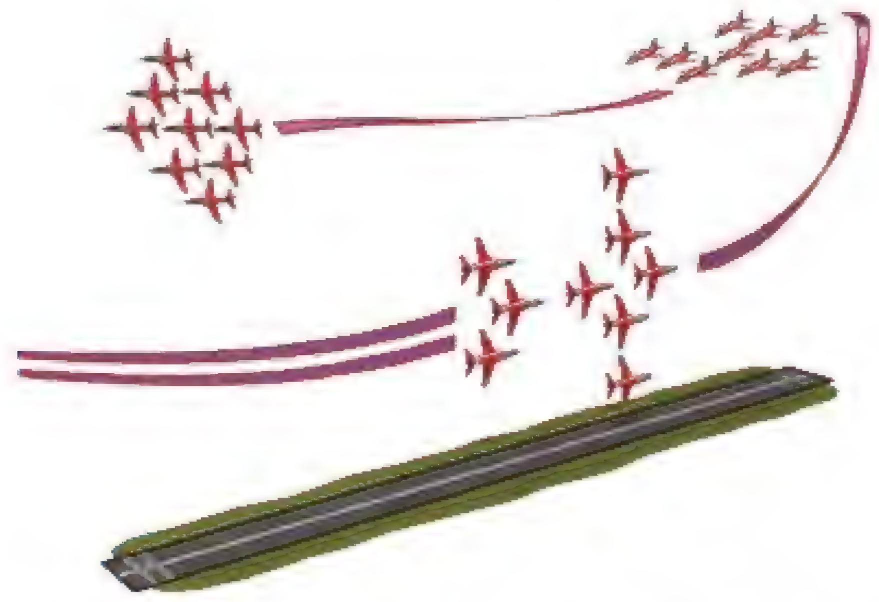
Although they do add something extra to the display visually, these vapour trails have a more important function. They enable pilots to judge wind speed and direction, and make it possible for the Team Leader and Synchro Leader to see each other even when separated by large distances. They are essential to flight safety.

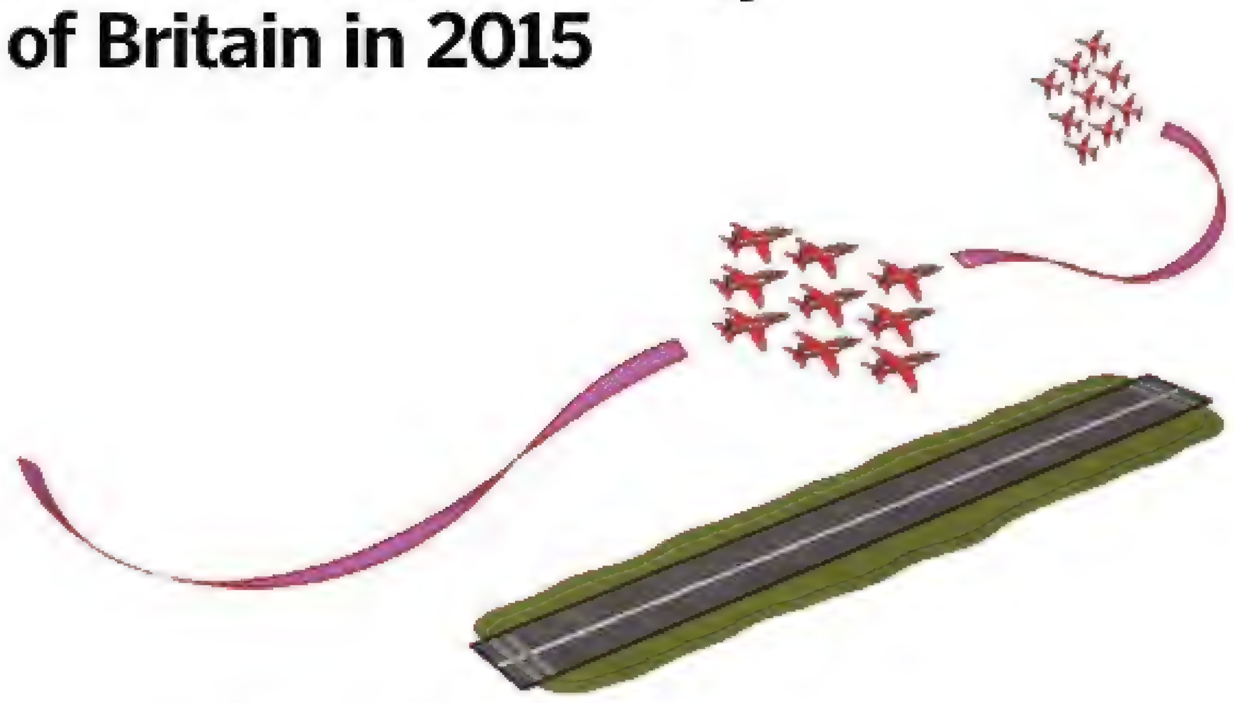
The Red Arrows can produce a vapour trail for seven minutes during a 30-minute display

"The first five Red Arrows planes (Reds 1 to 5) are the front part of the overall formation, known as 'Enid'"

DISPLAY MANOEUVRES

See the manoeuvres that were performed to mark the 75th Anniversary of the Battle of Britain in 2015



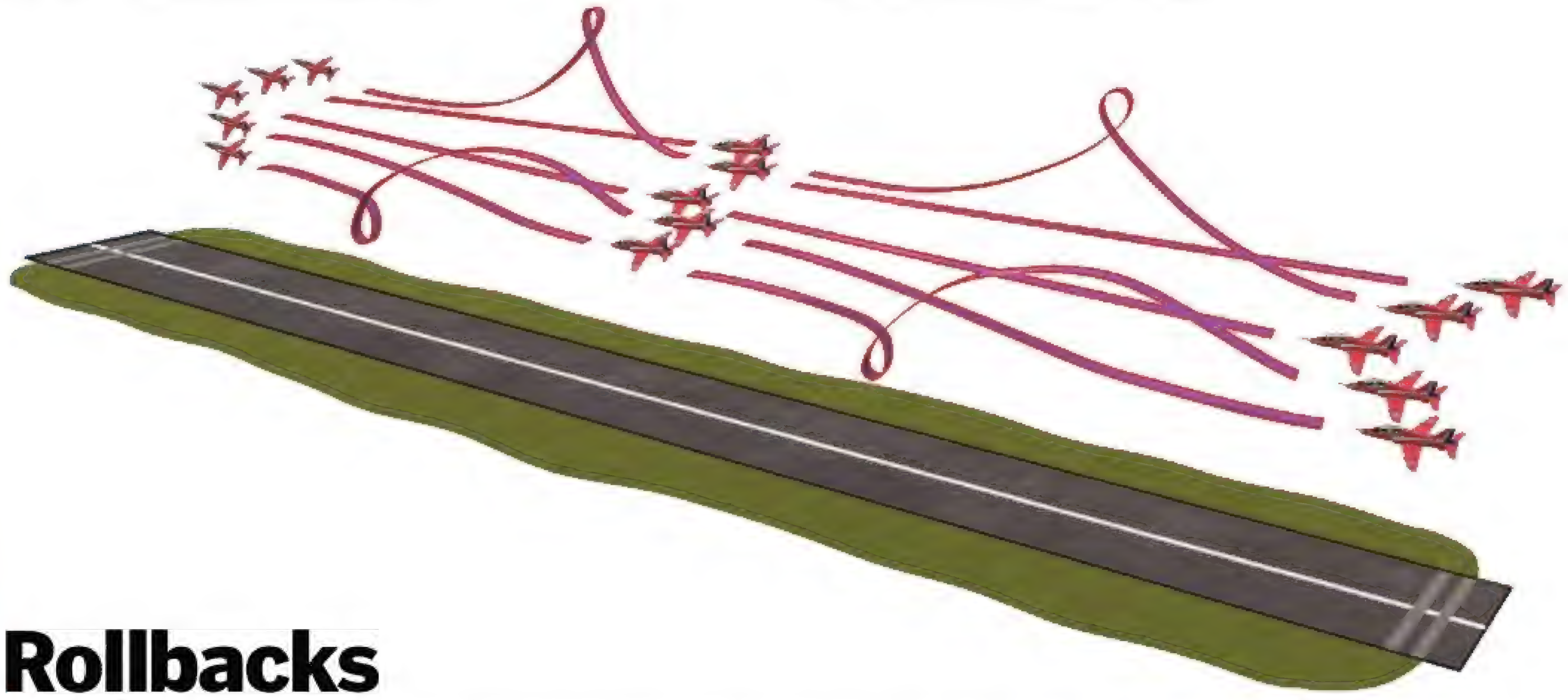


Spitfire Reversal

In recognition of the 75th anniversary of the Battle of Britain, the 2015 Red Arrows display featured them flying in the shape of a spitfire.

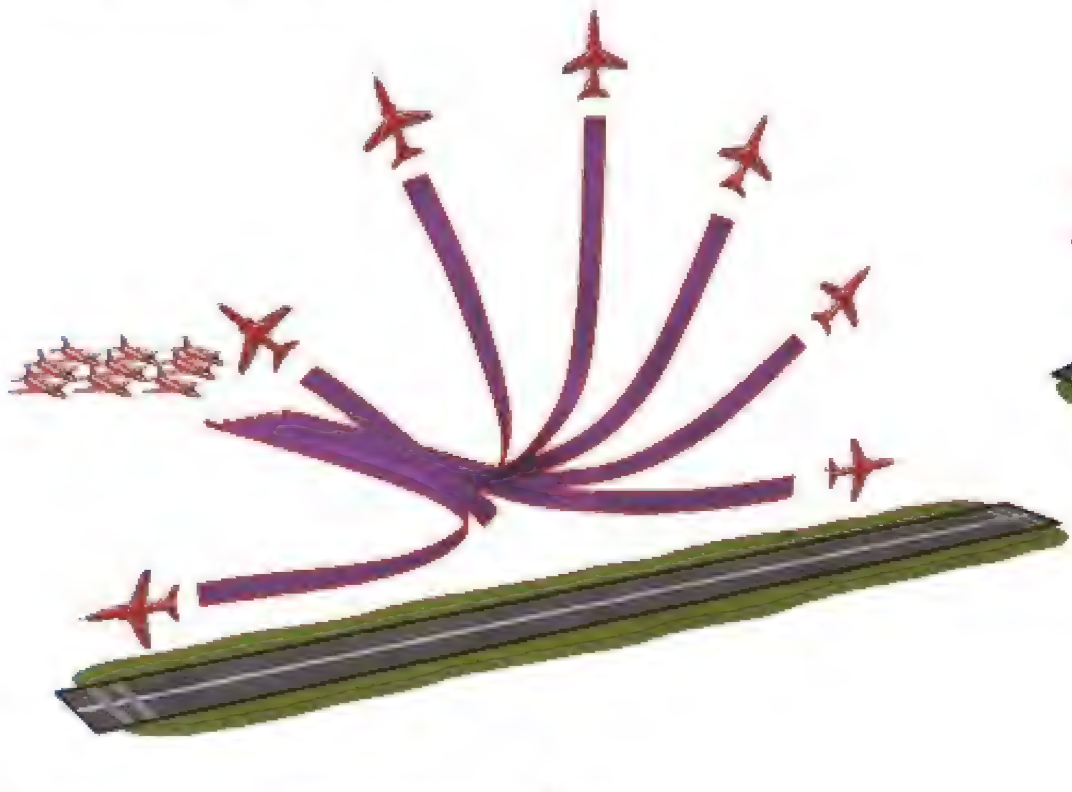
Whirlwind

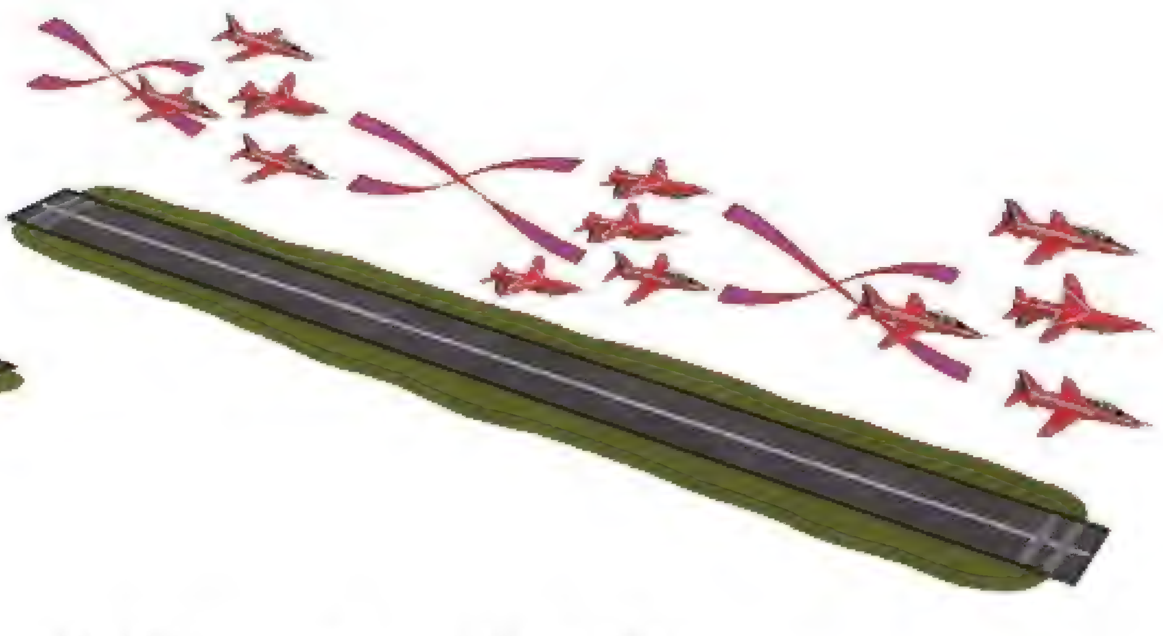
The Whirlwind was introduced for the 2015 Red Arrow displays and features all nine jets performing a roll followed by a Blackbird loop.



Rollbacks

Red 2 will pull out of the Diamond Nine formation and perform a full 360-degree roll around Red 4 and then himself outside of Red 4. At the same time, Red 3 will perform an identical manoeuvre around Red 5. The difficulty here is to keep the roll as tight as possible, and to time the rolls so that they are the same speed and look the same to the crowd.





Vixen Break

All planes fly directly towards the crowd, before breaking in different directions up and away from the crowd, pulling up to 7g. This is often a crowd favourite, but is one of the simplest manoeuvres to perform.

Mirror Roll

Throughout their 2015 displays, the Red Arrows revived the Mirror Roll which involved Red 6 performing an inverted barrel roll at -2.5g, while Reds 7, 8 and 9 remain in formation.

"The high speed-crossing manoeuvre is much easier than rolling into formation"

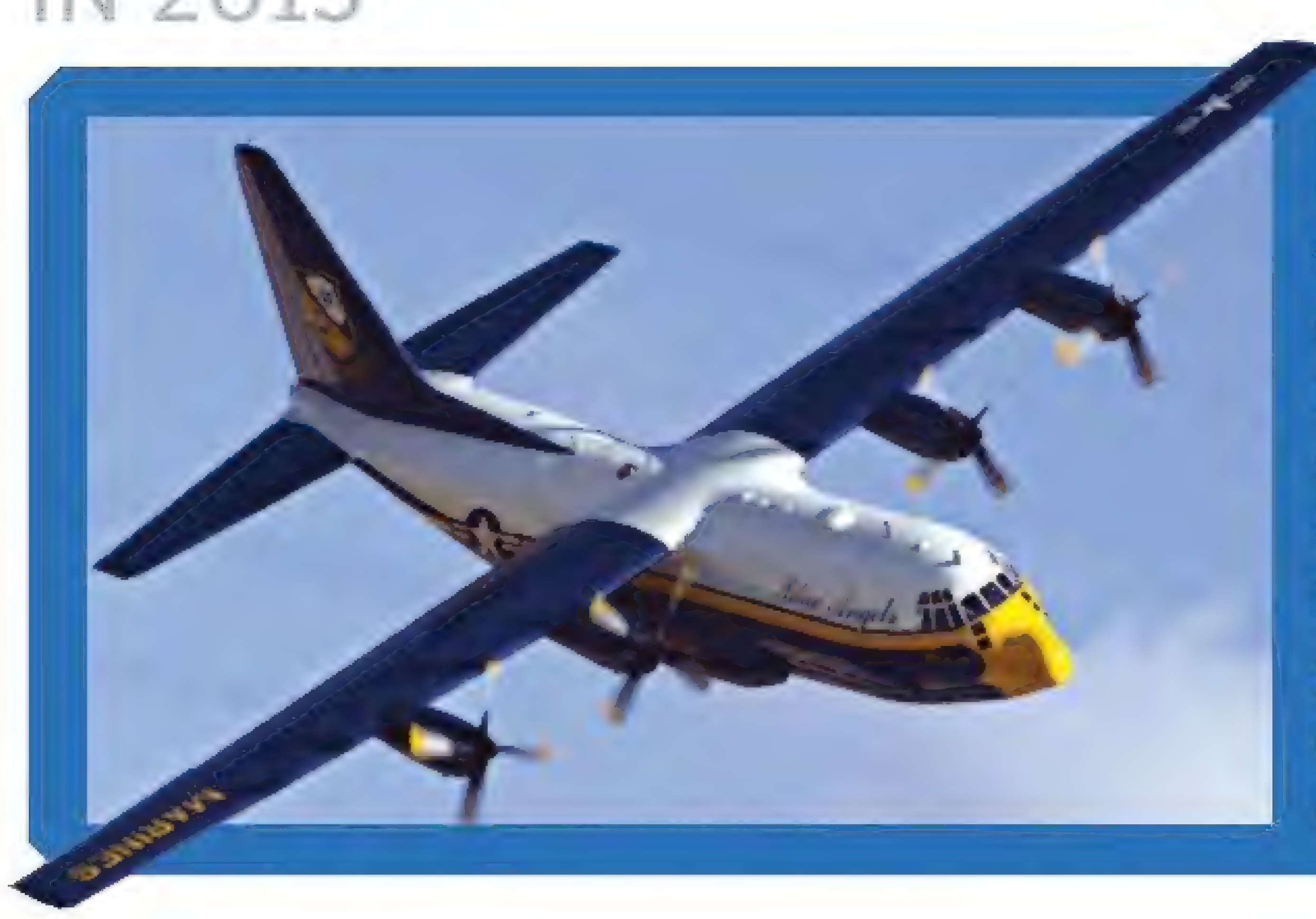
Inside the moves

Explore what makes the awe-inspiring manoeuvres work

All of the manoeuvres performed by the Blue Angels are difficult in their own way, but some of the stunts that look the hardest are actually the easiest. An example of this is the high speed-crossing manoeuvre, which is actually much easier to do than rolling into formation. This may look graceful, but it requires much more skill to perfect.

33 YEARS OLD
AVERAGE AGE OF A BLUE ANGEL PILOT

68
NUMBER OF SHOWS IN 2015



Fat Albert

Every show requires a huge behind-the-scenes effort. The Blue Angels use a C-130 Hercules to carry spare parts and support the many personnel that make their displays possible. Affectionately known as "Fat Albert", it has a range of 3,862 kilometres (2,400 miles) and can carry a colossal 20,412-kilogram (45,000-pound) payload.

Double Farvel

This manoeuvre involves the first four Blue Angels. They perform a flypast in a very tight diamond formation while two of the planes, Blue Angels 1 and 4, are inverted.

Knife Edge Pass

To perform this manoeuvre, two planes fly towards the same point at high speed, before suddenly altering their position so they pass each other. This can be performed as low as 15.24 metres (50 feet).

Section High Alpha Pass

This is the slowest manoeuvre the Blue Angels perform, and involves two of the jets slowing to 193km/h (120mph) as they pitch the noses of their planes up to an angle of 45 degrees.

1200 GALLONS (4,542 LITRES) JET FUEL BURNT PER HOUR

11 MILLION SPECTATORS PER YEAR (ABOUT THE SAME AS THE POPULATION OF GREECE)

© US Navy

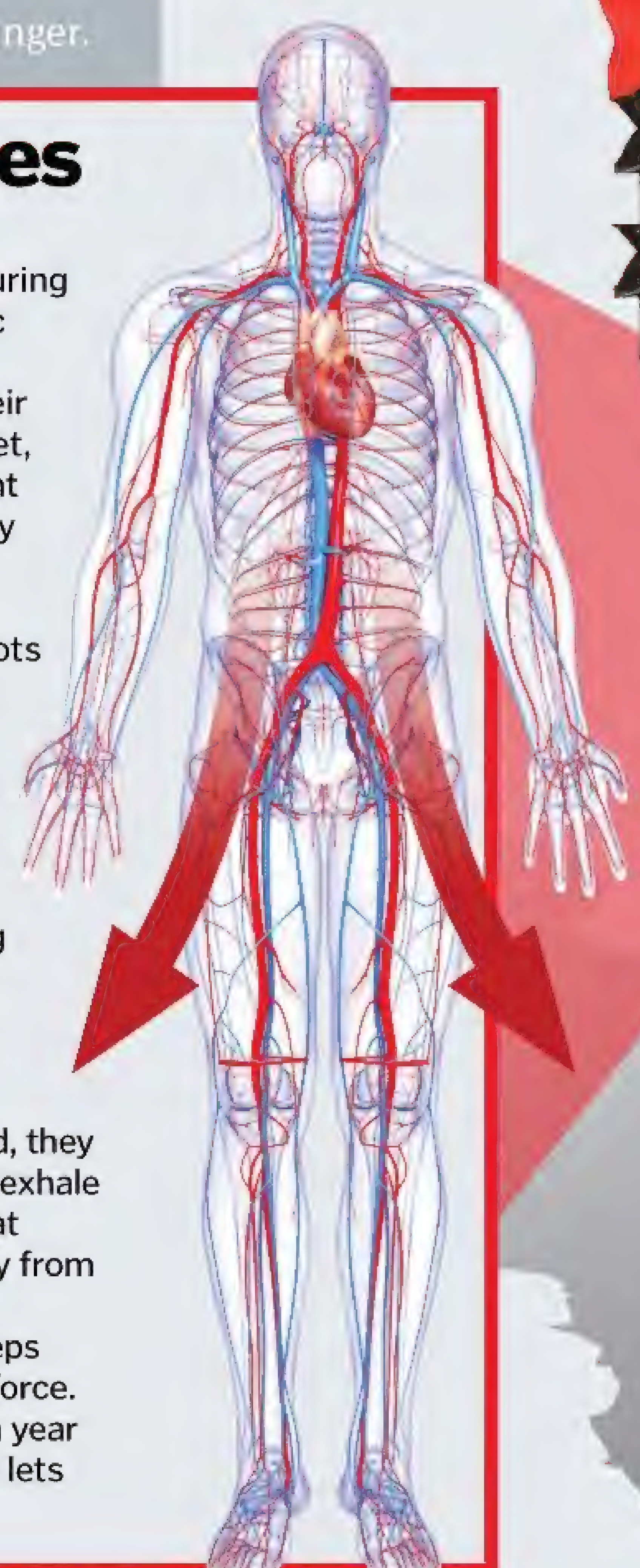
STAYING SAFE IN THE SKY

A number of steps are taken to keep aerobatic display pilots in one piece

The purpose of the Red Arrows and the Blue Angels is to thrill millions of spectators every year, but they never compromise on pilot safety. Due to the nature of their flying and the high number of shows they perform, accidents do happen, although they are less regular than they were when the aerobatic teams first performed. By studying both the pilots and the planes themselves, both teams are now aware of exactly how far man and machine can be pushed. Both the Blue Angel and the Red Arrow pilots wear specific safety equipment which enables them to perform their amazing displays with the minimum amount of danger.

Above: The Blue Angels wear their iconic yellow helmet but do not wear an oxygen mask during performances.

Combating g-forces



We measure gravity in terms of how much acceleration a force applies to an object. During some of their daring manoeuvres, aerobatic pilots will often be exposed to extreme gravitational forces. These forces direct their blood away from the brain towards their feet, causing the heart to stop pumping sufficient blood back to the brain which will eventually cause the pilot to totally blackout.

There are two ways that aerobatic pilots can counteract this problem. Red Arrow pilots wear a g-suit which employs a compressed air and bladder system. This compresses the legs and abdomen, reducing the likelihood of a blackout by reducing the amount of blood able to flow away from the brain.

Blue Angel pilots undergo specific training to enable them to fly without g-suits. This is because it is impossible to wear them when they fly, as they rest their forearms on their legs and use their knees as a fulcrum which the suits could interfere with if worn. Instead, they learn to tense their lower body muscles and exhale sharply (known as the 'hick' manoeuvre), that slows the rate at which the blood flows away from the brain. Blue Angel pilots are mandated to exercise at least six times a week, which keeps them fit and helps their bodies cope with g-force. On top of this, they train in a centrifuge each year which exposes them to extreme g-force and lets them practice dealing with its effects.

What it takes to be a display pilot

Learn about the rigorous interview and training that future pilots have to face

The interview process for selecting a new member of a display team is incredibly thorough. In the case of the Blue Angels, there has to be a completely unanimous (16-0) vote in favour of a candidate in order for them to join.

The Red Arrows will shortlist nine potential pilots via a pre-selection board, who are then invited for the seven-day interview. During this time, the candidates will undertake a flying test, meet the current team, accompany a Red Arrow pilot during a display practice and be formally interviewed. Once this has been completed, the current team will meet to decide which applicants have been successful.

Flight lieutenant Mike Bowden, who pilots Red 2, explains how first-timers learn to fly in unison: "When you fly in formation on the front line, you wait for the aircraft around you to move and copy what they do," he says. "If we were to do this in the Red Arrows it would make the overall formation look very broken, which is why we learn to follow voice commands from the Team Leader). We aim to perfect formation flying before moving to complex manoeuvres."

After meeting the initial criteria, Blue Angel applicants, or 'rushees' as they're fondly referred to, shadow the current pilots for numerous displays. They watch everything the existing team do, attend team briefs and go to social engagements. Candidates are then whittled down, with the remaining potential pilots put forward for a daunting one versus 16 interview, where all current Blue Angel pilots and officers ask the candidate a question.

After this, the current team sits down and decides which candidates will be joining the following year's team. We spoke to LCDR Mark Tedrow, the lead solo pilot for the Blue Angels, who revealed how they train: "The Blue Angels are so unique and the flying we do is very different to anything you do in the military – it really does feel like learning to fly all over again," he says. "Between the end of one season and the start of the next, we aim to accumulate 120 training flights. We are usually flying 15 times per week, which is a fairly gruelling schedule, but that means we can perform our manoeuvres practically from muscle memory."

Blue Angels recruits have to complete a variety of survival challenges before earning their qualifications to fly with the team

The experience you'll need to qualify

With only three spots available each year, gaining a place in a display team needs a very specific set of skills

RED ARROWS

Education

Many pilots are educated to degree level, but this isn't a requirement.

Experience

- ☑ Completed a frontline tour of duty.
- ☑ Assessed as being above average in their flying role.
- ☑ An exceptional flying record that includes reports on operational flights.

Flying Hours

A MINIMUM OF **1,500** HOURS IS EXPECTED.

Becoming Team Leader

To apply to become Team Leader, or the 'Boss', a pilot must have completed a three-year tour with the Red Arrows earlier in their career, which makes the number of people that can apply for this role limited. The Royal Air Force personnel department will select the officer they believe is best suited to carry out the wide range of duties expected of a Team Leader.

BLUE ANGELS

Education

Many pilots are educated to degree level, but this isn't a requirement

Experience

- ☑ Experience in an F/A-18.
- ☑ Carrier-qualified, active-duty Navy or Marine Corps tactical jet pilot.
- ☑ Combat experience, usually in landing on and taking off from aircraft carriers.

Flying Hours

A MINIMUM OF **1,250** FLYING HOURS IS EXPECTED.

Becoming 'The Boss'

The Chief of Naval Air Training selects the 'Boss', the Blue Angels commanding officer. The Boss must have at least 3,000 tactical jet flight-hours and have also commanded a tactical jet squadron. The Commanding Officer flies the Number 1 jet and leads all of the formations.

1938
Supermarine Spitfire
The Supermarine Spitfire was used by the RAF and other Allied forces during WWII. It was designed as a short-range, high-performance interceptor aircraft, with a maximum speed of 595km/h (370mph). Originally fitted with eight .303 Browning machine guns, it helped defend Britain's coastline during the Battle of Britain.

1989
Harrier II
Introduced to active service in December 1989, the Harrier II is an example of a vertical and/or short-takeoff and landing (V/STOL) jet aircraft, perfect for use on aircraft carriers. It was frequently used in combat during missions in Kosovo, Iraq and Afghanistan.

1983
F-117 Nighthawk
The F-117 Nighthawk was equipped with pioneering stealth technology and was designed to have a minimal radar cross-section, making it very hard to detect by traditional monostatic radars. During its 25 years of service, only one was ever lost in combat.

CELEBRATING FIGHTER

FROM WWI TO MODERN DAY, INSIDE THE MOST ICONIC MILITARY AIRCRAFT

From daring dogfights over World War I France, to the computer-powered prowess of the modern era's jet fighters, the history of aerial warfare is nearly as old as flight itself.

In 1915, Dutch engineer Anton Fokker devised an interrupter gear, a simple mechanism that allowed a fixed machine gun to fire through a plane's running propeller blades. The first plane to use this was the Fokker Eindecker, which was so effective it began what the British Royal Flying Corps referred to as the 'Fokker Scourge'. This sparked an international race to create faster, more manoeuvrable and ever-more destructive aircraft.

By the end of the Great War, the tactical advantages of maintaining air superiority were well established and by 1939 and the dawn of the Second World War, another leap in aerial combat was already dominating the skies. Capable of hitting speeds of over 500 kilometres (311 miles) per hour, the Messerschmitt Bf 109 was over three times faster than the Eindecker. From its testing ground in the skies of the Spanish Civil War to the

DID YOU KNOW? *Frenchman Adolphe Pégoud was named the first flying ace of WWI after shooting down five German aircraft*

1916
Sopwith Pup
Equipped with a rotary engine and weighing only 357kg (787lb), it had a range of over 300km (186mi). It was armed with only a single Vickers machine gun and has a fabric-covered, wooden framework. It was nicknamed the 'Pup' as it was smaller than the two-seat Sopwith 1.5 Strutter.

1949
F-86 Sabre
First used in 1949, the F-86 Sabre was used by more than 20 different nations prior to its eventual retirement in 1994. An example of a swept-wing, transonic jet fighter aircraft, it also featured a 'flying tail', which gave it superb manoeuvrability at altitude.

2005
Lockheed Martin F-22 Raptor
The F-22 Raptor is the leading stealth tactical fighter aircraft. Its F-119 engines are regarded as the most advanced ever produced. Pilots benefit from 360-degree awareness when flying. Their ability to super-cruise at Mach 1.5 without afterburners makes them particularly lethal.

100 YEARS OF PLANES

invasions of Poland and France, this powerful, lightweight and well-armed fighter set a new precedent for fighter planes.

Aerial warfare was now recognised as the key to strategic success on the ground. Luckily, Allied machines, such as the Rolls Royce-powered Spitfire that was already in service at the outbreak of the war, were able to out-class their German rivals. In the final months of the war, however, the future of fighter aircraft had already taken to the skies. Though it came too late and in too small a number to turn the tide of the war for Hitler, the Messerschmitt Me 262 was the first-ever jet fighter, capable of speeds of 870 kilometres (541 miles) per hour.

Some of the last propeller-powered combat was seen in the Korean War of 1950 to '53, before the world fully entered into the jet age. The skies of the Cold War became tensely patrolled by Soviet MiG-15s, American F-15 fighters and some of the fastest planes ever engineered. Then specialist vertical takeoff and landing (VTOL) aircraft were developed for deployments on aircraft carriers, while secret stealth and surveillance technology was covertly advanced to wage the war in the shadows.

In modern warfare the job of the fighter plane is still a crucial element. The new generation of computer-assisted jets are capable of more roles and simultaneous operations than ever before; reducing the risk to the pilot, increasing the threat to the enemy and ensuring complete dominance of the skies.

Modern-day tech

How the new generations of military tech changed the face of aerial warfare

Ever since the Messerschmitt Me 262, nicknamed the Swallow, first took flight in World War II, the jet age has seen fighter-plane technology soar. One key difference between the fighters of today and their ancestors is the need for flexibility. While warplanes were previously designed for specific tasks – such as fighter bombers, escort, or reconnaissance – today's aircraft are expected to perform a range of roles, even simultaneously. For example, the Eurofighter Typhoon carries over a dozen brackets under its fuselage. This enables it to carry any combination of air-to-air or ground-attack armament, or extra fuel pods for prolonged sorties, fulfilling the potential for every combat role.

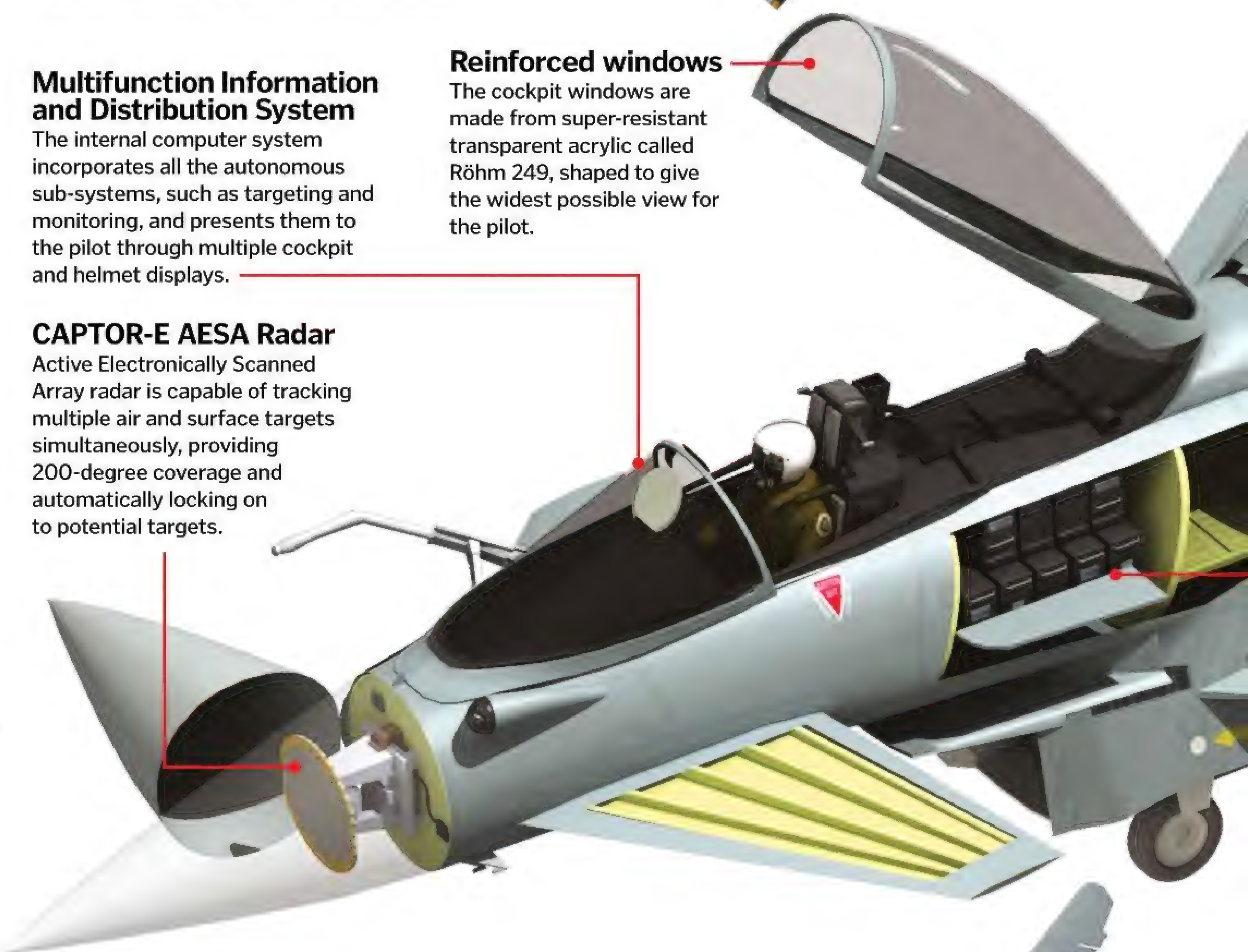
With machines becoming ever faster and weapons systems leaving little to no room for error, even the lightning reactions of the hardiest flying maverick would struggle to last five minutes of air combat – that is, without the aid of computer technology. Though it goes without saying the role of a pilot still demands incredible levels of skill, endurance, multitasking and quick reactions under pressure, the onboard computer is now an essential component of any fighter plane.

The heads-up display (HUD), iconic from films such as *Top Gun*, was among the most important electronic upgrades to the cockpits of fighter jets. It relays target tracking, sensor, navigation and other data direct to the pilot. The HUD computer is connected to all the external and internal sensors of the aircraft, so it's able to collate, prioritise and even give guidance based on this data. This has enabled pilots to quickly engage various threats, enact countermeasures and even land safely, all while keeping two eyes firmly focused on the danger zone.

Though within the last few decades fighter technology has leapt several generations, in step with the growing capabilities of computers, the principles of assisting pilot operation have remained the same. For example, the Human Machine Interface (HMI) and Flight Control System (FCS) of the Eurofighter accommodates voice input/output controls, Autopilot, Autothrottle and Flight Director Modes, all to assist handling. In addition, its latest generation of radar is able to identify and prioritise threats. With all this, it's no wonder fighter pilots still feel a special bond with these incredible machines.

Typhoon Tranche 3 Eurofighter

The technology inside Europe's £100 million fighter will take your breath away



Multifunction Information and Distribution System

The internal computer system incorporates all the autonomous sub-systems, such as targeting and monitoring, and presents them to the pilot through multiple cockpit and helmet displays.

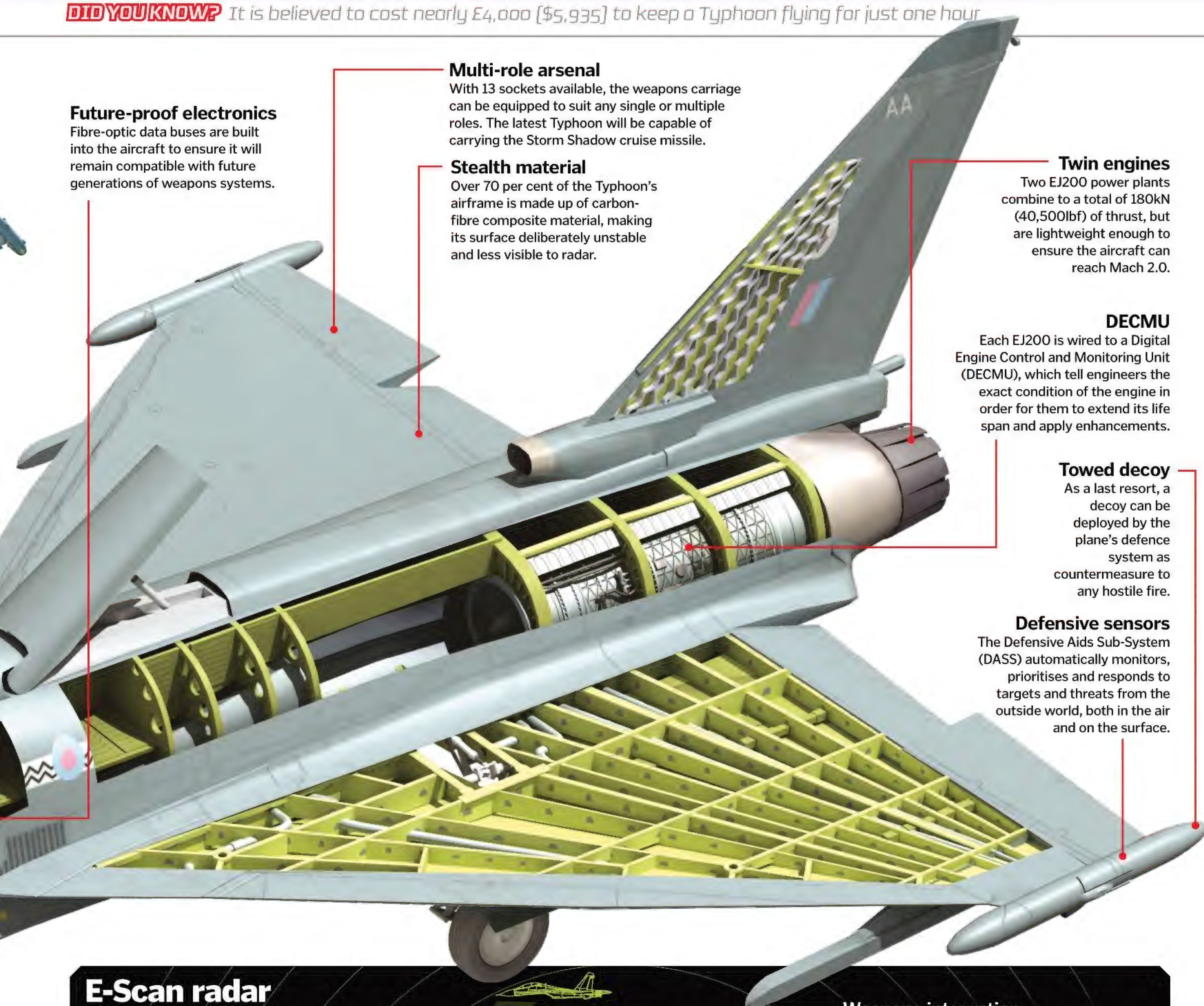
Reinforced windows

The cockpit windows are made from super-resistant transparent acrylic called Röhm 249, shaped to give the widest possible view for the pilot.

CAPTOR-E AESA Radar

Active Electronically Scanned Array radar is capable of tracking multiple air and surface targets simultaneously, providing 200-degree coverage and automatically locking on to potential targets.

DID YOU KNOW? *It is believed to cost nearly £4,000 [$5,935] to keep a Typhoon flying for just one hour*



Multi-role arsenal
With 13 sockets available, the weapons carriage can be equipped to suit any single or multiple roles. The latest Typhoon will be capable of carrying the Storm Shadow cruise missile.

Future-proof electronics
Fibre-optic data buses are built into the aircraft to ensure it will remain compatible with future generations of weapons systems.

Stealth material
Over 70 per cent of the Typhoon's airframe is made up of carbon-fibre composite material, making its surface deliberately unstable and less visible to radar.

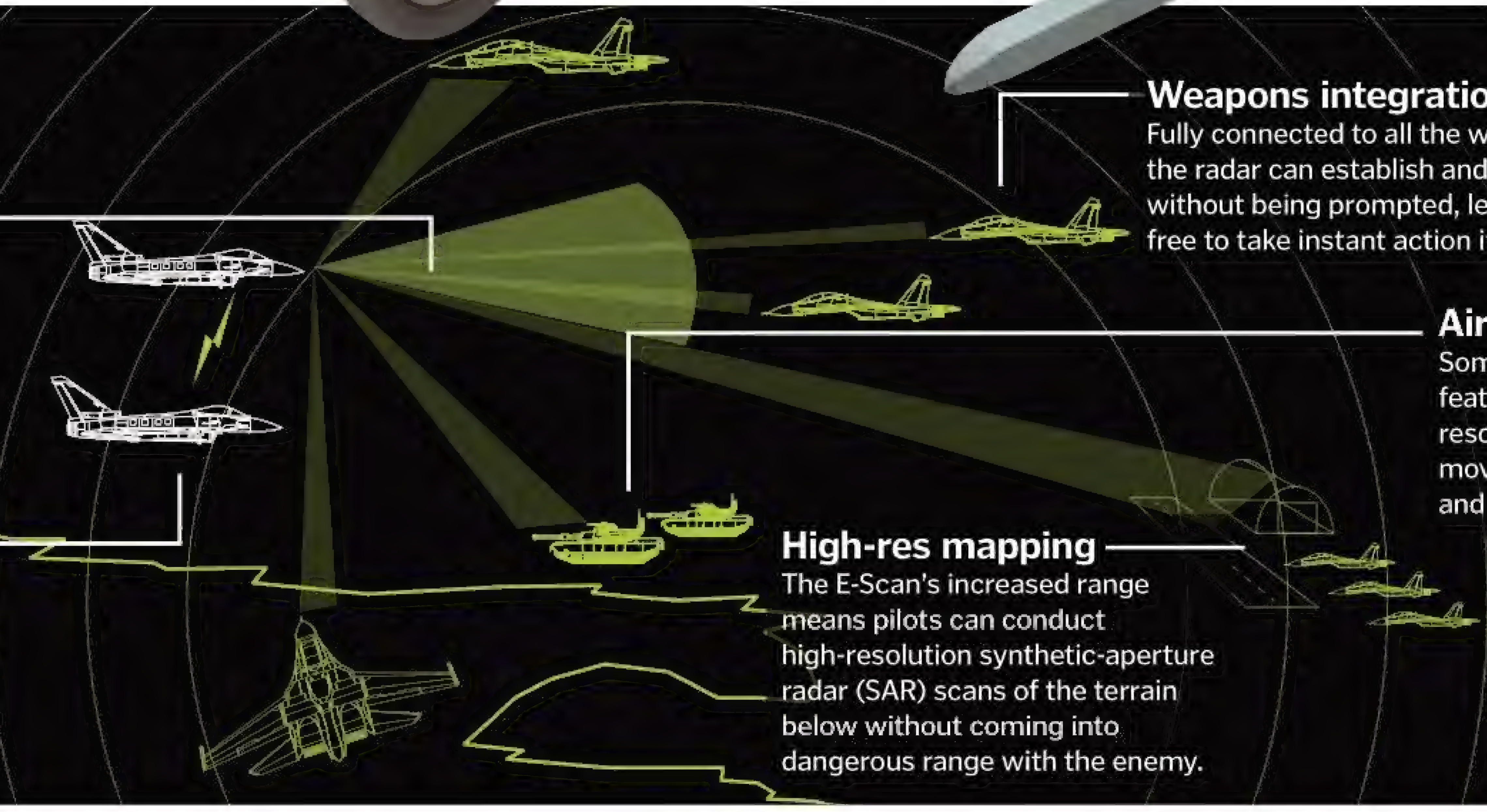
Twin engines
Two EJ200 power plants combine to a total of 180kN (40,500lbf) of thrust, but are lightweight enough to ensure the aircraft can reach Mach 2.0.

DECMU
Each EJ200 is wired to a Digital Engine Control and Monitoring Unit (DECMU), which tell engineers the exact condition of the engine in order for them to extend its life span and apply enhancements.

Towed decoy
As a last resort, a decoy can be deployed by the plane's defence system as countermeasure to any hostile fire.

Defensive sensors
The Defensive Aids Sub-System (DASS) automatically monitors, prioritises and responds to targets and threats from the air outside world, both in the air and on the surface.

E-Scan radar
This watchful eye doesn't miss a thing



Wide view
The E-Scan is capable of monitoring multiple targets simultaneously, both ground and airborne, giving the pilot a 200-degree view of the battlefield.

Data link
As well as its primary radar functions, the E-Scan keeps pilots in contact with one another through Data Link capabilities.

Weapons integration
Fully connected to all the weapons systems, the radar can establish and lock on to targets without being prompted, leaving the pilot free to take instant action if required.

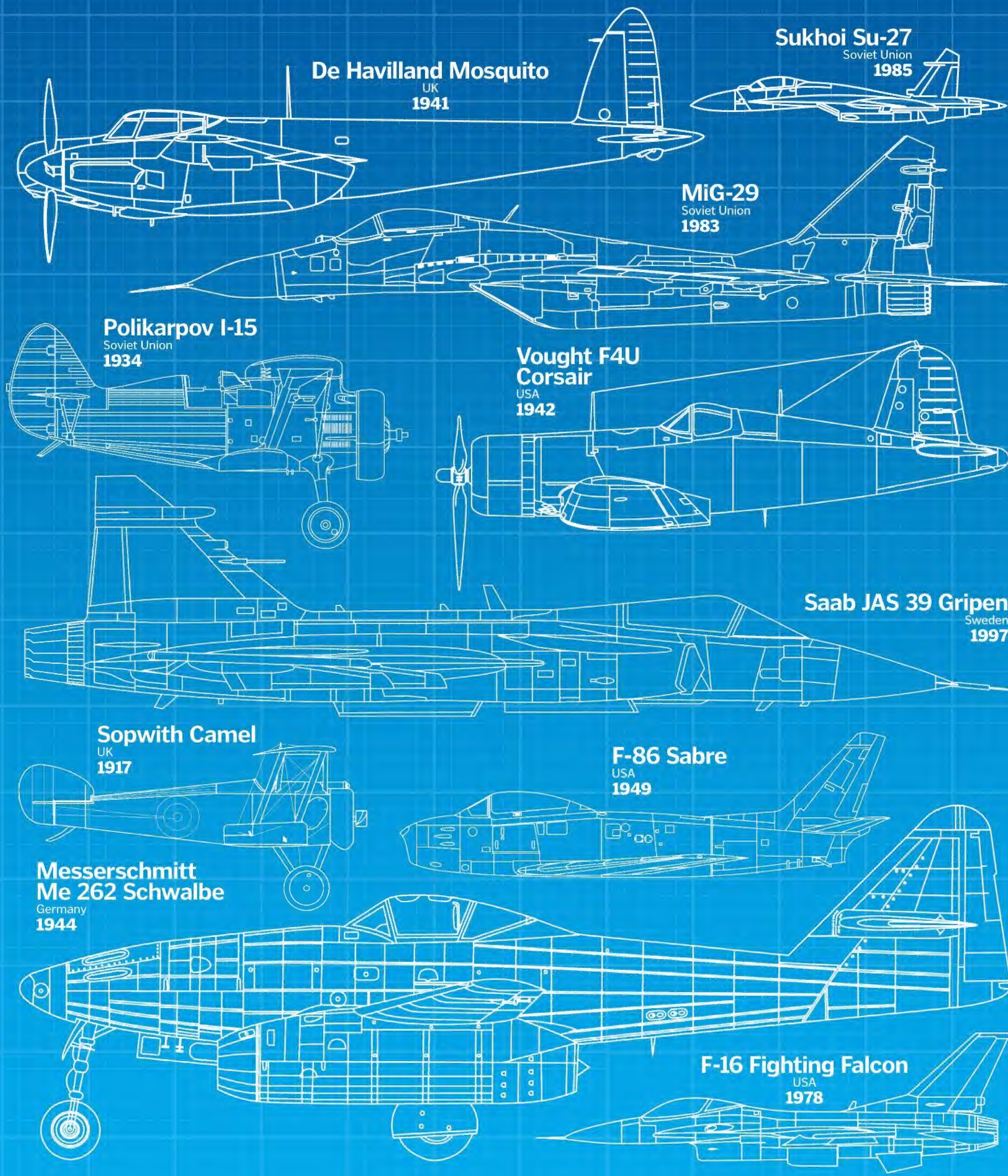
Air-to-ground ability
Some of the air-to-ground features include high-resolution maps, ground moving target identification and air-to-surface ranging.

High-res mapping
The E-Scan's increased range means pilots can conduct high-resolution synthetic-aperture radar (SAR) scans of the terrain below without coming into dangerous range with the enemy.

AVIATION HISTORY

Discover how warplanes have developed through the ages

DID YOU KNOW? *The F-100 Super Sabre was the first-ever US fighter plane to achieve supersonic speeds*



Evolution of the fighter plane

How the old war dogs of the skies reached new heights in their time

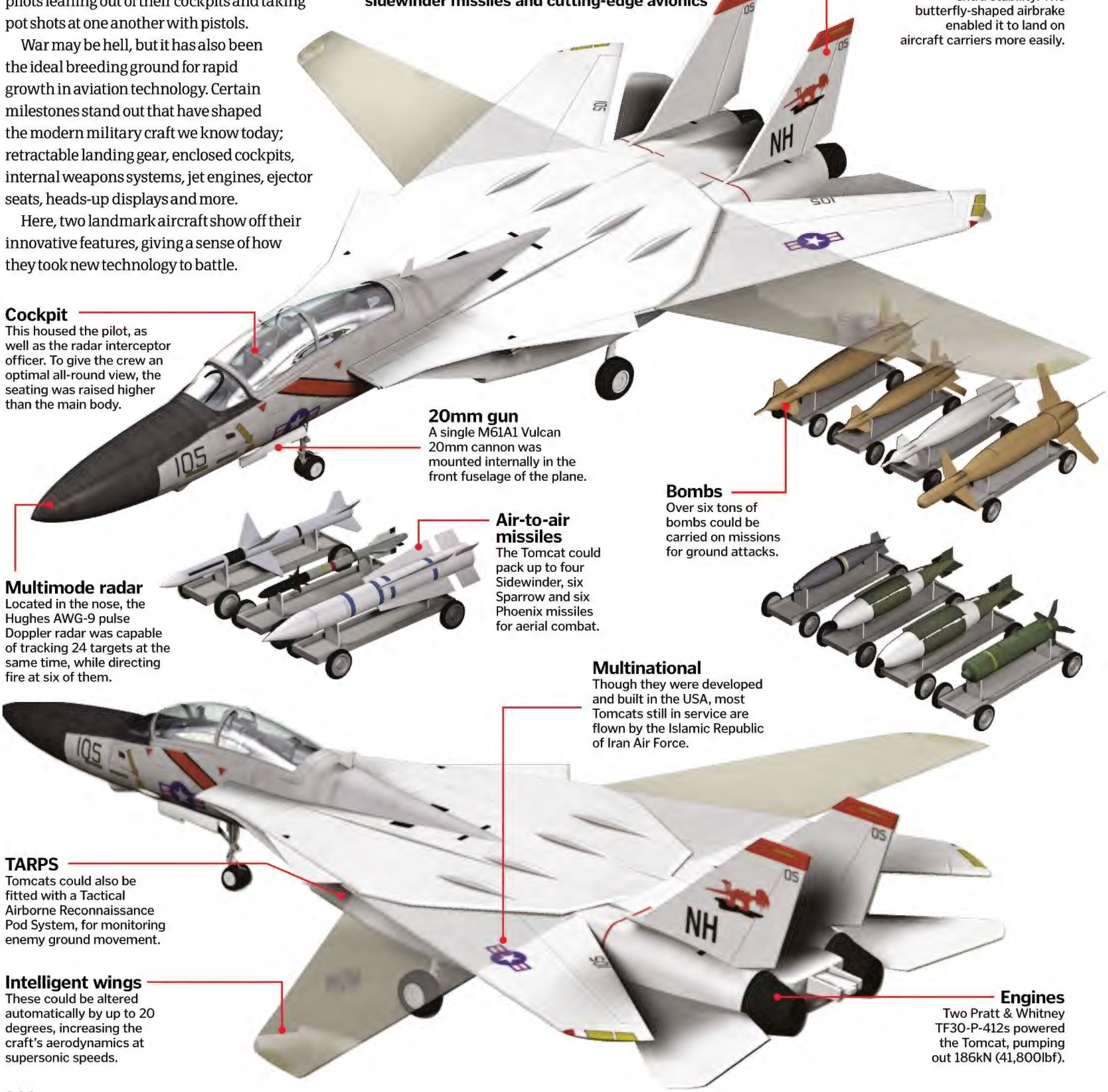
Almost as soon as we were able to fly, we have been inventing new ways to destroy one another in the air. Aerial combat has come a long way from pilots leaning out of their cockpits and taking pot shots at one another with pistols.

War may be hell, but it has also been the ideal breeding ground for rapid growth in aviation technology. Certain milestones stand out that have shaped the modern military craft we know today; retractable landing gear, enclosed cockpits, internal weapons systems, jet engines, ejector seats, heads-up displays and more.

Here, two landmark aircraft show off their innovative features, giving a sense of how they took new technology to battle.

Grumman F-14A Tomcat

A cat with formidable claws – in the shape of sidewinder missiles and cutting-edge avionics



Tail
This twin tail gave the plane extra stability. The butterfly-shaped airbrake enabled it to land on aircraft carriers more easily.

Cockpit
This housed the pilot, as well as the radar interceptor officer. To give the crew an optimal all-round view, the seating was raised higher than the main body.

20mm gun
A single M61A1 Vulcan 20mm cannon was mounted internally in the front fuselage of the plane.

Bombs
Over six tons of bombs could be carried on missions for ground attacks.

Air-to-air missiles
The Tomcat could pack up to four Sidewinder, six Sparrow and six Phoenix missiles for aerial combat.

Multimode radar
Located in the nose, the Hughes AWG-9 pulse Doppler radar was capable of tracking 24 targets at the same time, while directing fire at six of them.

Multinational
Though they were developed and built in the USA, most Tomcats still in service are flown by the Islamic Republic of Iran Air Force.

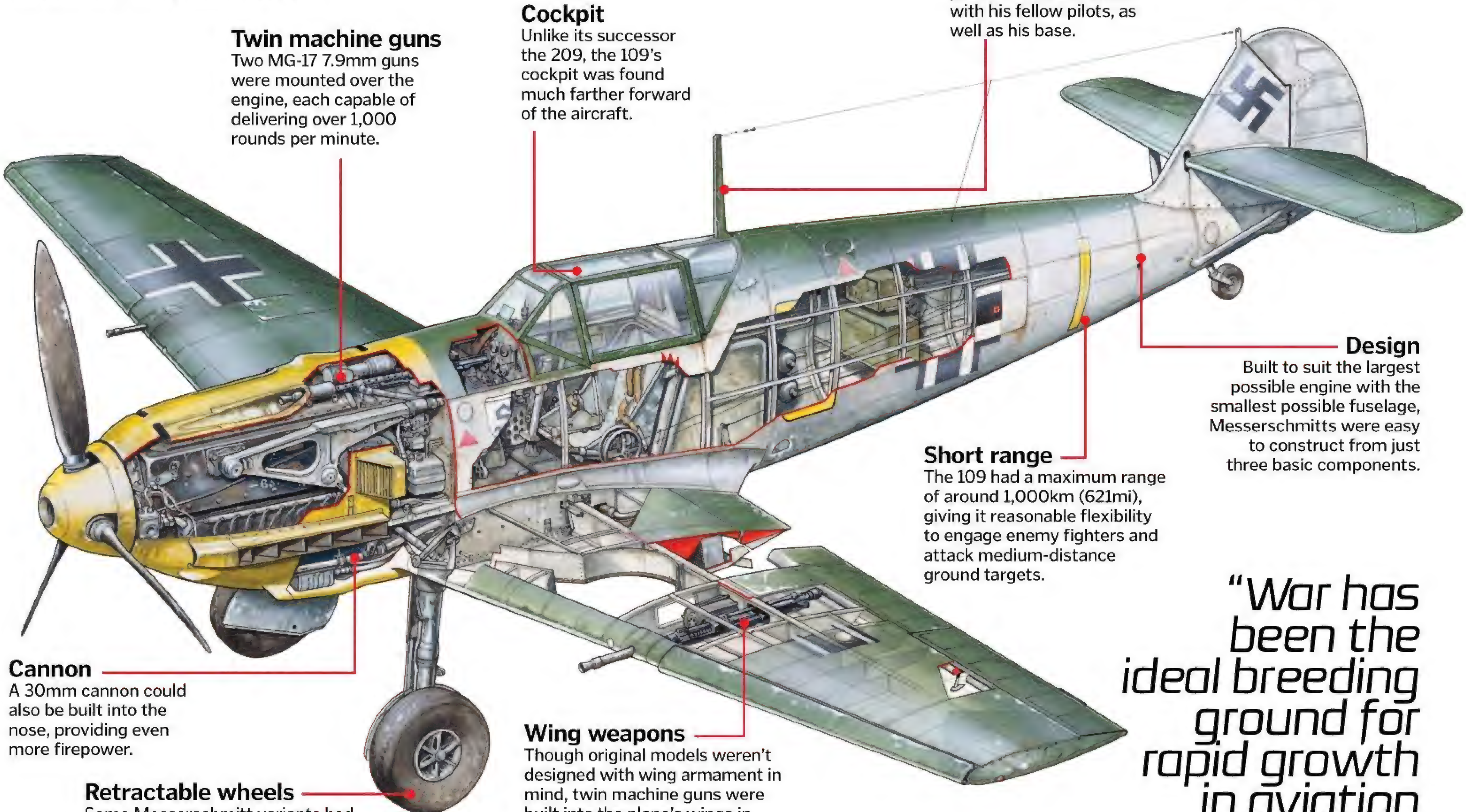
TARPS
Tomcats could also be fitted with a Tactical Airborne Reconnaissance Pod System, for monitoring enemy ground movement.

Intelligent wings
These could be altered automatically by up to 20 degrees, increasing the craft's aerodynamics at supersonic speeds.

Engines
Two Pratt & Whitney TF30-P-412s powered the Tomcat, pumping out 186kN (41,800lbf).

Messerschmitt Bf 109

This scourge of the skies dominated the battles over early WWII Europe



Antenna
A high-frequency antenna, connected to a FuG 16Z radio, kept the pilot in communication with his fellow pilots, as well as his base.

Cockpit
Unlike its successor the 209, the 109's cockpit was found much farther forward of the aircraft.

Twin machine guns
Two MG-17 7.9mm guns were mounted over the engine, each capable of delivering over 1,000 rounds per minute.

Design
Built to suit the largest possible engine with the smallest possible fuselage, Messerschmitts were easy to construct from just three basic components.

Short range
The 109 had a maximum range of around 1,000km (621mi), giving it reasonable flexibility to engage enemy fighters and attack medium-distance ground targets.

Cannon
A 30mm cannon could also be built into the nose, providing even more firepower.

Retractable wheels
Some Messerschmitt variants had retractable landing gears, which made them more aerodynamic.

Wing weapons
Though original models weren't designed with wing armament in mind, twin machine guns were built into the plane's wings in response to the heavily armed British Spitfires.

"War has been the ideal breeding ground for rapid growth in aviation technology"

The future of warplanes

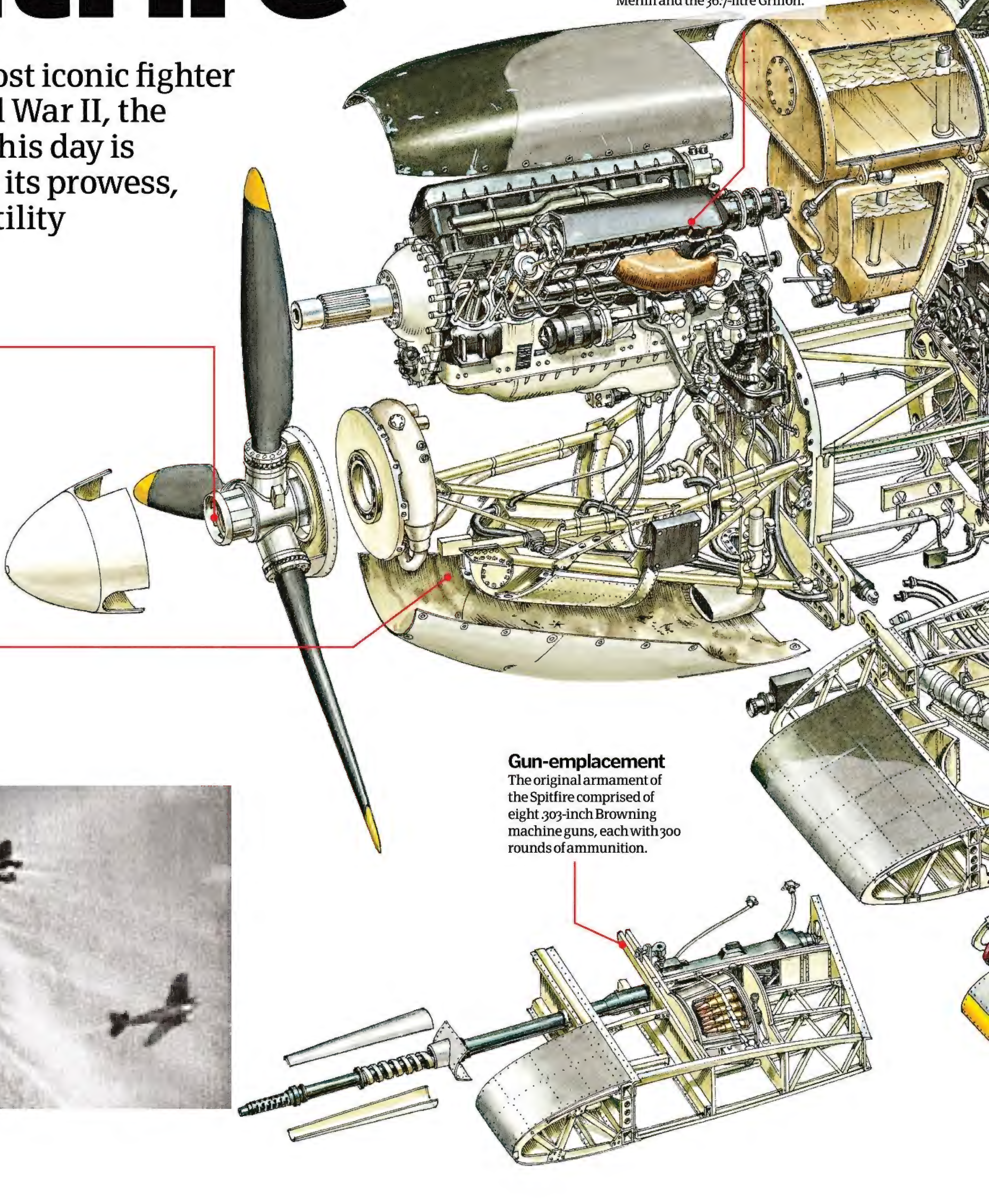
With the increasing use of unmanned drones to target and monitor enemy positions and combatants, it has been suggested that traditional fighter jets could eventually lose any purpose in future warfare. In 2013 the Northrop Grumman X-47B prototype unmanned aircraft was the first of its kind to perform a carrier-launch and recovery, signalling a possible future of unmanned strike-bomber aircraft. Boeing's QF-16s – retired F-16 jets modified to be controlled remotely – are now regularly used for aerial target training. While these pilotless jets are used as real-life targets to test missile systems, they demonstrate just how accurate remote flight is becoming.

Both government and industry leaders have admitted that future military aircraft will have to be more closely integrated with artificial intelligence, even with suggestions that manned jets may work alongside pilotless craft. Studies by the Defense Advanced Research Projects Agency (DARPA) have revealed that drones operate more effectively in packs, prompting further research into how drones could work with one another, rather than rely solely on human controllers in combat scenarios. Even before the fifth generation of fighter jets become widely available, including the F-35 Lightning II and Shenyang J-31, world governments are already looking at cost-effective, as well as cutting-edge solutions for the sixth generation of military aeronautics.

The F-35 Lightning II is currently the fifth-generation of fighter aircraft for several global Air Forces and Navies

Supermarine Spitfire

Arguably the most iconic fighter aircraft of World War II, the RAF Spitfire to this day is championed for its prowess, grace and versatility



Rolls-Royce Vee-12 engine
The Spitfire utilised two variant of Rolls-Royce engine during its production life span, the 27-litre Merlin and the 36.7-litre Griffon.

Propeller
Original Spitfires had wooden propellers, these were later replaced with variable-pitch propellers, and more blades were added as horsepower increased.

Airframe
The aircraft's airframe was an amalgamation of a streamlined semi-single piece of aluminium alloy with an enclosed cockpit, allowing increased responsiveness and ease of flight.

Gun-emplacement
The original armament of the Spitfire comprised of eight .303-inch Browning machine guns, each with 300 rounds of ammunition.

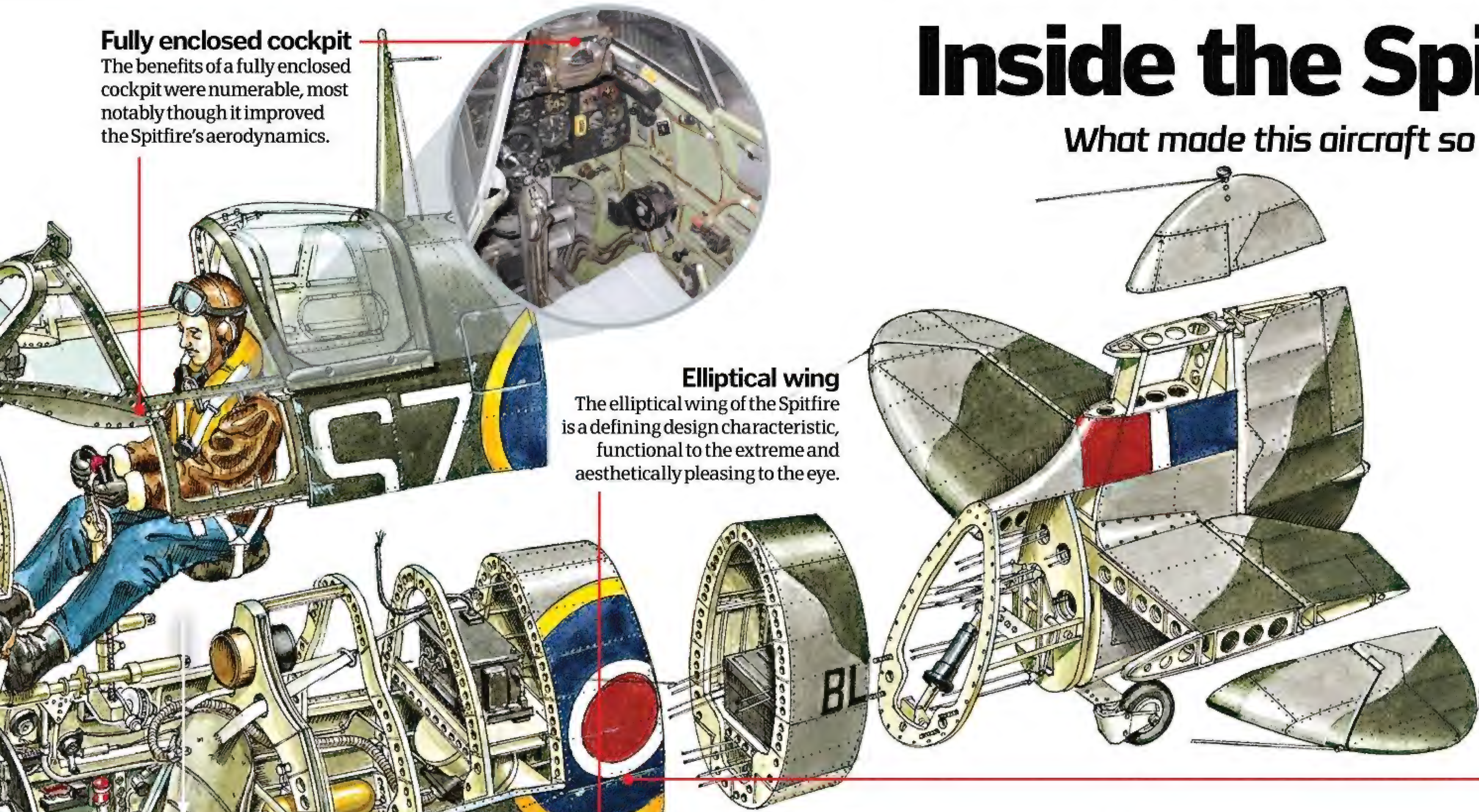
Video still from gun camera showing the tracers

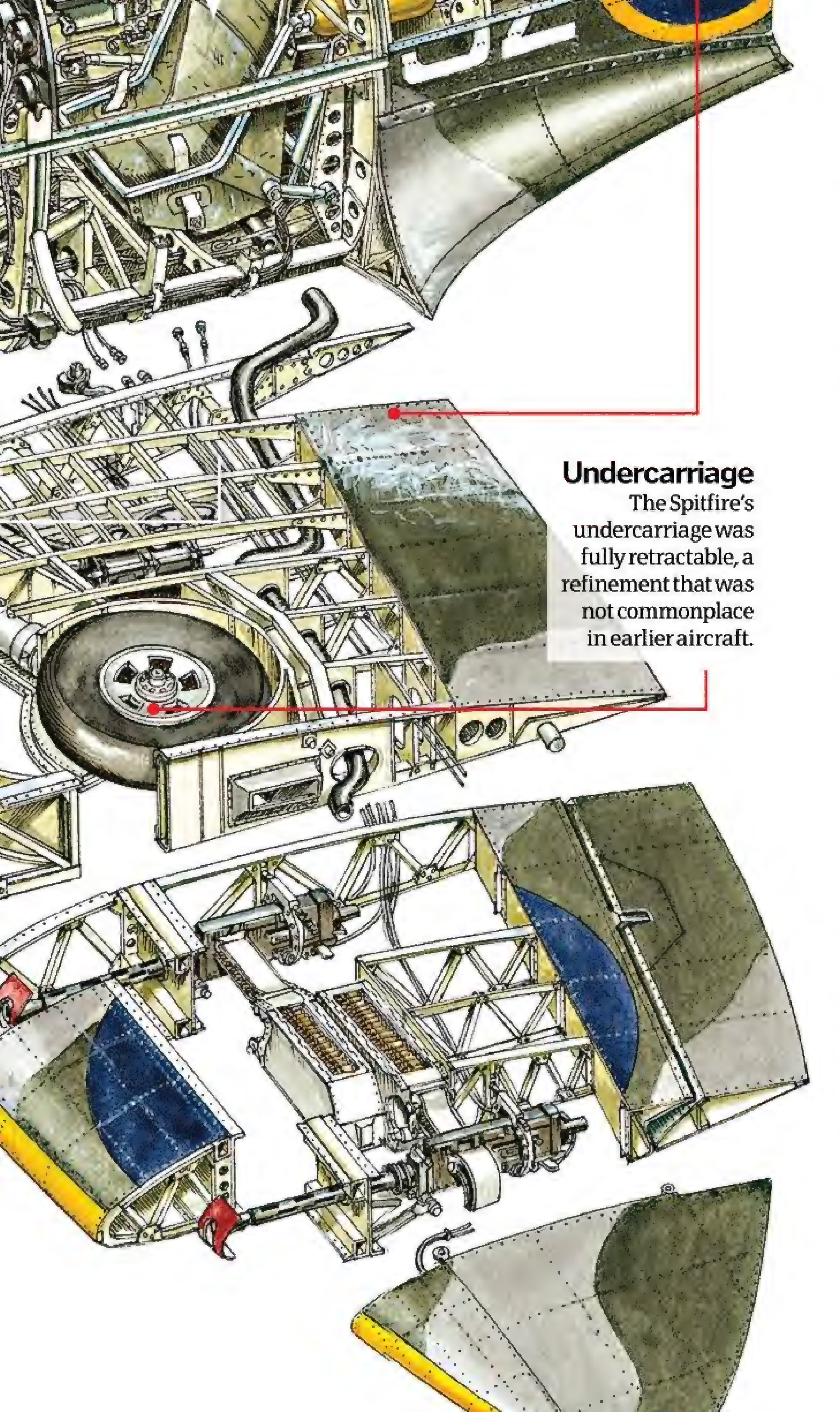
MAX SPEED 450mph **RANGE** 400 miles **LENGTH** 32ft 11ins
WINGSPAN 36ft 11in **ARMAMENT** 20mm cannon x4

DID YOU KNOW? *By 1939, approximately ten per cent of all Spitfires had been lost as a result of training accidents*

Inside the Spitfire

What made this aircraft so spectacular?





Designed in the technologically fervent and innovatory melting pot of World War II, the Supermarine Spitfire became the fighter plane of the times. With its simple lines, elegant frame and superb aerodynamics, the Spitfire was to live on in the minds of generations during the war and for many decades to come.

The Supermarine Spitfire was the brainchild of aeronautical engineer Reginald Mitchell, who led a dedicated and talented team of designers. Originally planned as a short-range air-defence fighter, the Spitfire was built for speed and agility, traits that it was to need in the explosive dogfights it was to partake in as it met enemy fighters and bombers. Building a fighter plane, though, is more complex than listing desirable traits however, and the Spitfire's construction is a balletic series of compromises between weight, aerodynamics and firepower.

The frame of a Spitfire with its elliptical wings is one of its most defining characteristics, casting a distinctive silhouette against the sky. The ellipse shaping was used to minimise drag while having the necessary thickness to accommodate the retracted undercarriages and the guns required for self defence. A simple compromise that had the resulting benefit of having an incredibly individual shape. In contrast, the airframe – which was influenced by exciting new advances in all metal, low-wing plane construction – was a complex and well-balanced amalgamation of a streamlined semi-single piece of aluminium alloy and a fully enclosed cockpit. This allowed unrivalled responsiveness and ease of flight, making the Spitfire a favourite for pilots.

Arguably, the other most defining and success-inducing element of the Spitfire was its engine, which took on the form of the Rolls-Royce Merlin and Griffon engines. Planned by a board of directors at Rolls-Royce who realised that their current Vee-12 engine was topping out at 700hp and that a more powerful variant would be needed, first the Merlin and later the Griffon engines were designed. The Merlin at first delivered 790hp, short of the 1,000hp goal set in its design brief, however this was to increase to 975hp in a few years. The Griffon then built upon the success of the Merlin, delivering at the climax of its advancement a whopping 2,035hp. These engines were to prove tantamount to the airframe and wing designs in the dominance of the Spitfire.

Despite its origins lying in short-range home defence, the Spitfire was to prove so versatile and successful that it was quickly adapted for a wide variety of military purposes. Many variants were created, including designs tailored for reconnaissance, bombing runs, high-altitude interception and general fighter-bomber operations. The most notable derivative, however, was the multi-variant Seafire, specially designed for operation on aircraft carriers with the added ability to double-fold its wings for ease of storage.

Considering the place in history that the Spitfire holds – a fighter-bomber aircraft that bridged the gap between the age of the propeller engine to that of the jet – the fact that they are still collected (with an average cost of £1.4 million) and flown today is unsurprising. The Spitfire is a timeless piece of engineering that shows some of the most creative and advanced efforts in military history.

Lancaster bomber

Famed for its prowess and entrenched in popular culture by The Dam Busters film of 1955, the Lancaster bomber played a vital role in securing an Allied victory in World War II

Arguably one of the most famous heavy bombers of World War II, the Avro-built Lancaster bomber undertook some of the most dangerous and complex missions yet encountered by the RAF. Primarily a night bomber but frequently used during the day too, the Lancasters under Bomber Command flew some 156,000 sorties during the war, dropping 609,000 tons of bombs. Among these bombs was the famous 'bouncing bomb' designed by British inventor Barnes Wallis, a payload that would lead the Lancaster to remain famed long after 1945. We take a look inside a Avro Lancaster to see what made it so successful.

Lancaster bombers dropped 609,000 tons of bombs

Inside a Lancaster bomber

Crew

Due to its large size, hefty armament and technical complexity, the Lancaster bomber had a crew of seven. This included: a pilot, flight engineer, navigator, bomb aimer, wireless operator, mid-upper and rear gunners. Many crew members from Lancasters were awarded the Victoria Cross for their heroic actions in battle, a notable example being the two awarded after a daring daytime raid on Augsburg, Germany.

Turrets

As standard the Lancaster bomber was fitted with three twin 7.7mm turrets in the nose, rear and upper-middle fuselage. In some later variants of the Lancaster the twin 7.7mm machine guns were replaced with 12.7mm models, which delivered more power. The rear and upper-middle turrets were staffed permanently by dedicated gunners, while the nose turret was staffed periodically by the bomb aimer when caught up in a dogfight.

Bomb bay

The bomb bay could carry a great payload. Indeed, the bay was so spacious that with a little modification it could house the massive Grand Slam "earthquake" bomb, a 10,000kg giant that when released would reach near sonic speeds before penetrating deep into the Earth and exploding.

Fuselage

The Lancaster was designed out of the earlier Avro Type 683 Manchester III bomber, which sported a three-finned tail layout and was similar in construction. While the overall build remained similar the tri-fin was removed in favour of a twin-finned set up instead. This is famously one of only a small number of design alterations made to the bomber, which was deemed to be just right after its test flights.

5 TOP FACTS LANCASTER BOMBER

High calibre

1 While 7.7mm machine guns were standard on Lancaster bombers, selective later variants were fitted with twin 12.7mm turrets in both tail and dorsal positions.

Slam-dunk

2 Lancaster bombers often had their already-large bomb bays modified in order to carry the monumental 10,000 kilogram Grand Slam "earthquake" bombs.

Busted

3 A selection of bombers became famous after Operation Chastise, a mission to destroy German dams in the Ruhr Valley, the inspiration for the film *The Dam Busters*.

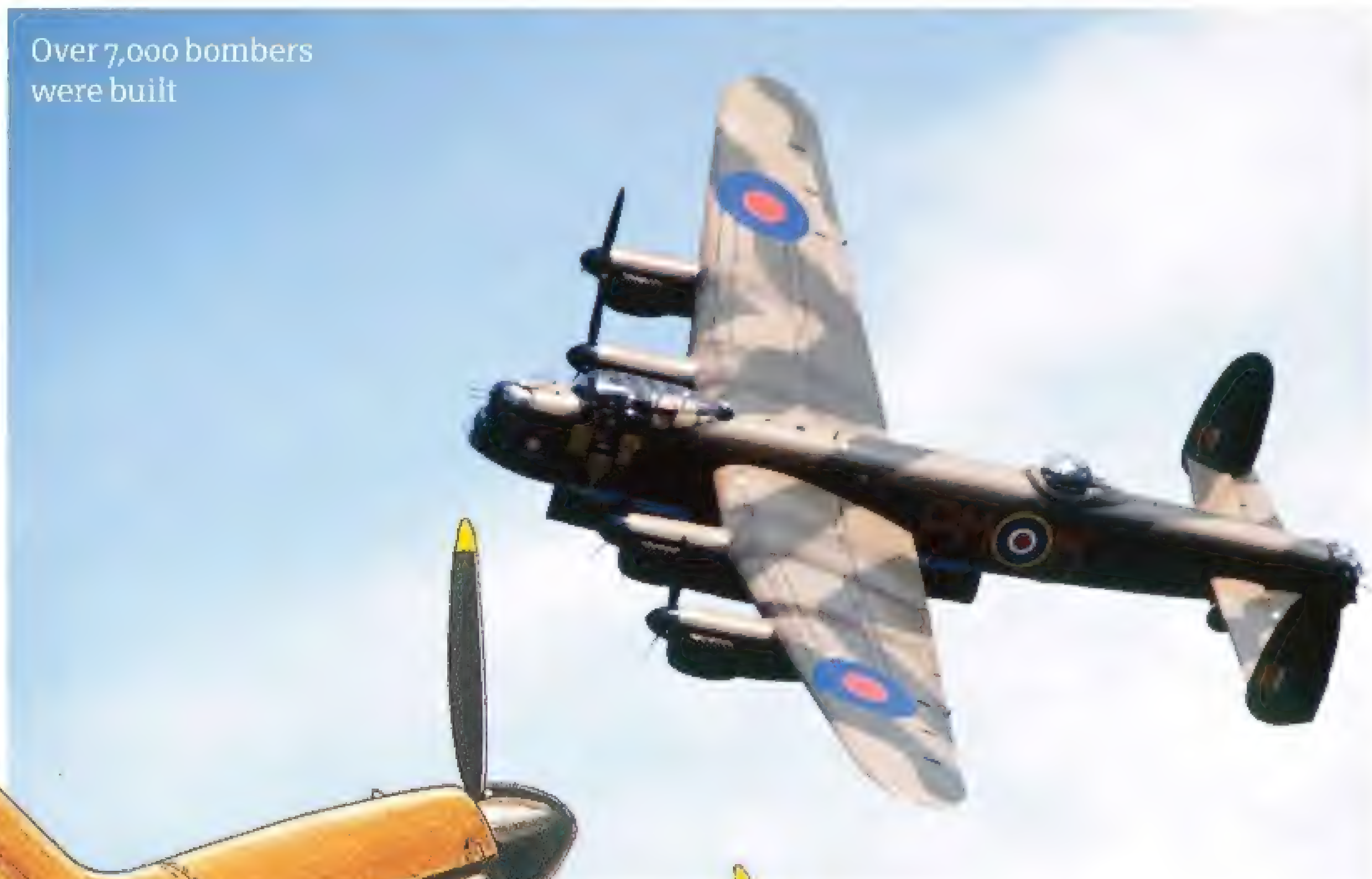
Collateral

4 Between 1942 and 1945 Lancaster bombers flew 156,000 sorties and dropped approximately 609,000 tons of bombs on military and civilian targets.

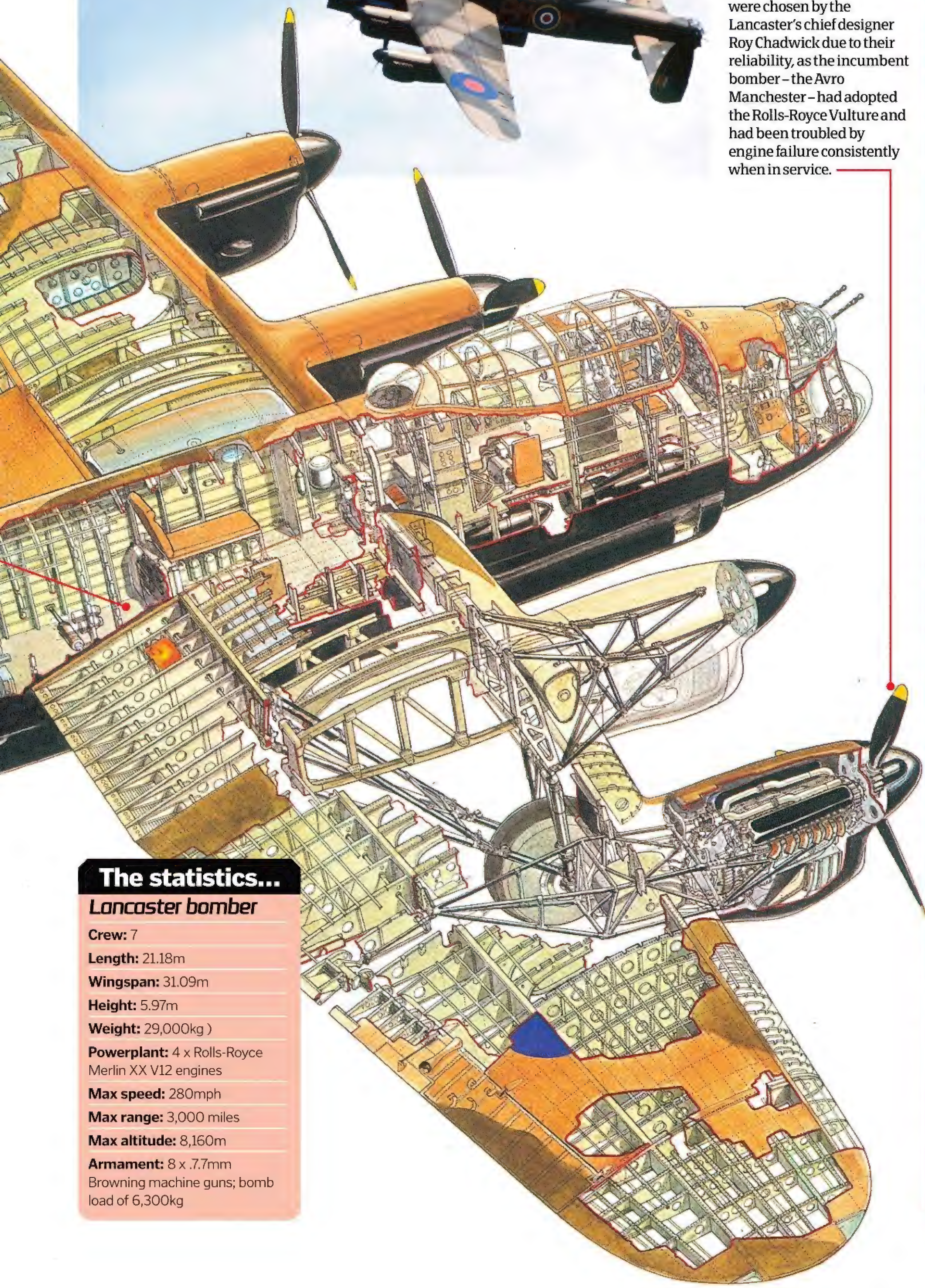
Black label

5 The lager company Carling used footage of Lancaster bombers to create a parody of *The Dam Busters* in which a German soldier catches the bouncing bombs.

DID YOU KNOW? A single Lancaster bomber cost £50,000 in 1942, roughly £1.5 million in today's currency



Over 7,000 bombers were built



Powerplant

The Lancaster bomber was powered by four Rolls-Royce Merlin V12 engines. These were chosen by the Lancaster's chief designer Roy Chadwick due to their reliability, as the incumbent bomber – the Avro Manchester – had adopted the Rolls-Royce Vulture and had been troubled by engine failure consistently when in service.

The statistics...

Lancaster bomber

Crew: 7
Length: 21.18m
Wingspan: 31.09m
Height: 5.97m
Weight: 29,000kg)
Powerplant: 4 x Rolls-Royce Merlin XX V12 engines
Max speed: 280mph
Max range: 3,000 miles
Max altitude: 8,160m
Armament: 8 x .7.7mm Browning machine guns; bomb load of 6,300kg

© Bluemoose

The bouncing bomb

One of the most famous parts of the Lancaster's heritage is its role in carrying and releasing the 'bouncing bomb' payload, as glamourised in the 1955 film *The Dam Busters*. The bomb was designed by Barnes Wallis – who was also the creator of the Grand Slam and Tallboy bombs – and was special in its ability to bounce along the top of a surface of water, much akin to skimming a stone. It was designed to counteract and evade German defences below and above the waterline, allowing Allied forces to target German hydroelectric dams and floating vessels.

In May 1943 the bouncing bombs were utilised in Operation Chastise, an allied mission to destroy German dams in the Ruhr Valley. The aircraft used were modified Avro Lancaster Mk IIIs, which had much of their armour and central turret removed in order to accommodate the payload. Despite eight of the Lancasters being lost during the operation, as well as the lives of 53 crew, a small number of bouncing bombs were released and they caused two dams to be breached, one to be heavily damaged and 1,296 civilians to be killed.

That's a real dam buster...

© John Batchelor / www.johnbatchelor.com

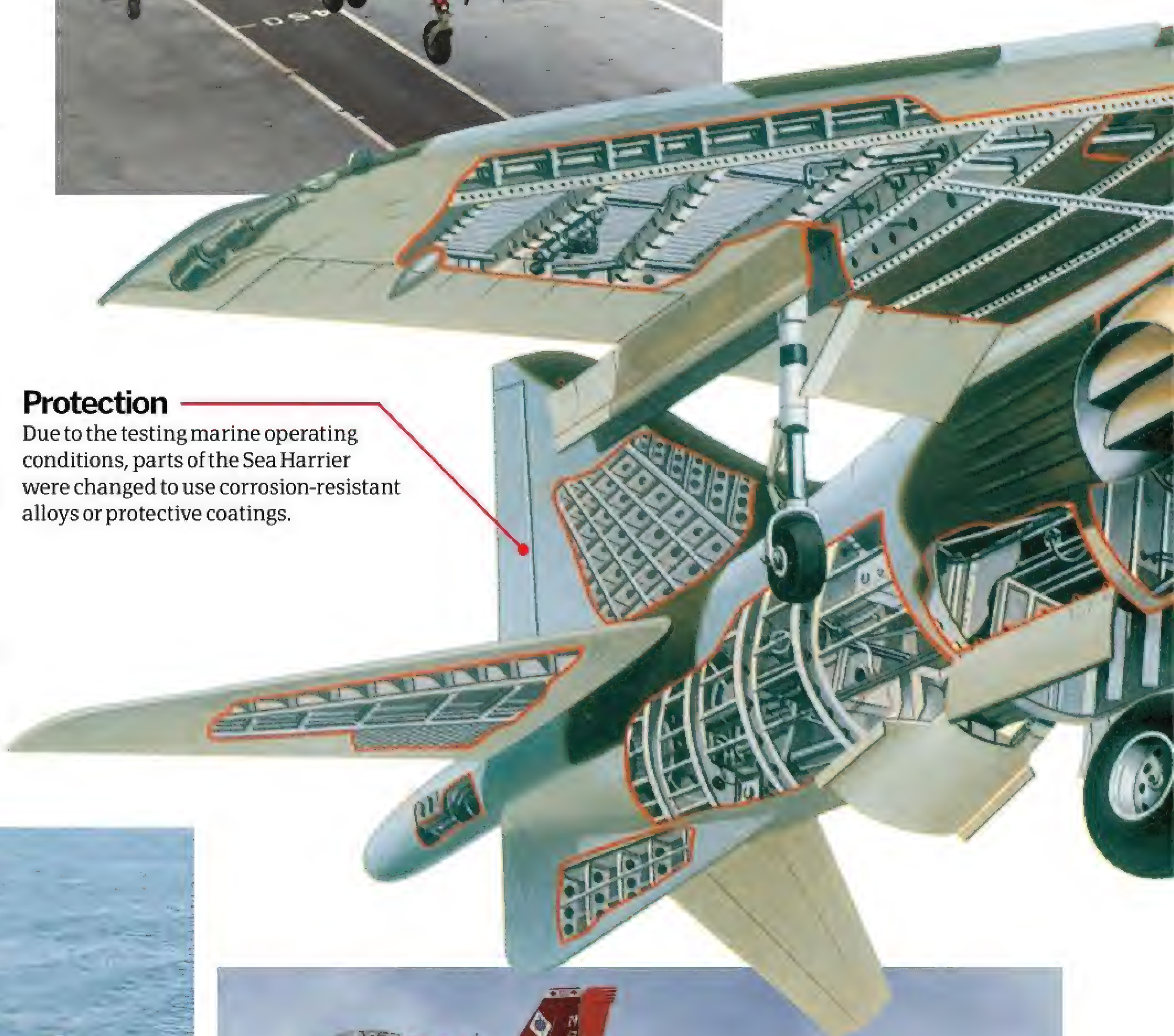
"The Sea Harrier squadron achieved this due to their high manoeuvrability"

Sea Harrier

Before being retired in 2006, the Sea Harrier dominated the subsonic jet fighter field, changing the dynamics and operation of the strike fighter role forever

The British Aerospace Sea Harrier was the purpose-built naval variant of the Hawker Siddeley Harrier strike fighter, an aircraft famed for its vertical take-off and landing (VTOL) and short take-off and vertical landing (STOVL) capabilities. It worked by adopting the revolutionary single-engine thrust vectoring technology of the regular harrier (see 'Degrees of power' boxout) and partnering it with a modified fuselage – to allow the installation of the superb Blue Fox radar system – bubble-style canopy (larger, allowing greater visibility) and a significantly improved arms load out.

These factors, partnered with the aircraft carrier's ability to launch the aircraft from its ski-jump, allowed the Sea Harrier to perform to a high standard at sea, carrying more weight, detecting enemies sooner and taking them down quickly and efficiently. This was demonstrated most vividly during the Falklands War of 1982, when 28 Sea Harriers operating off British aircraft carriers shot down 20 Argentine aircraft in air-to-air combat without suffering a single loss. The Sea Harrier squadron achieved this due to their high manoeuvrability and tactics while in dogfights – for example, braking/changing direction fast by vectoring their thrust nozzles while in forward flight – as well as their pilots' superior training and early-warning/detection systems.



Thrust vectoring
To achieve VTOL capabilities, the Sea Harrier's engine thrust was directed through four vectoring nozzles, which could rotate through 98.5 degrees from vertically downwards to horizontal.

Protection
Due to the testing marine operating conditions, parts of the Sea Harrier were changed to use corrosion-resistant alloys or protective coatings.

Second-generation Sea Harriers on board an aircraft carrier in the Persian Gulf

Two Indian Navy Sea Harriers fly alongside a US Navy F/A-18F Super Hornet

5 TOP FACTS
HARRIERS

Old boy
1 The Sea Harrier was in service for a total of 28 years, from August 1978 to March 2006. The second-generation Sea Harrier FA2 was introduced in April 1993.

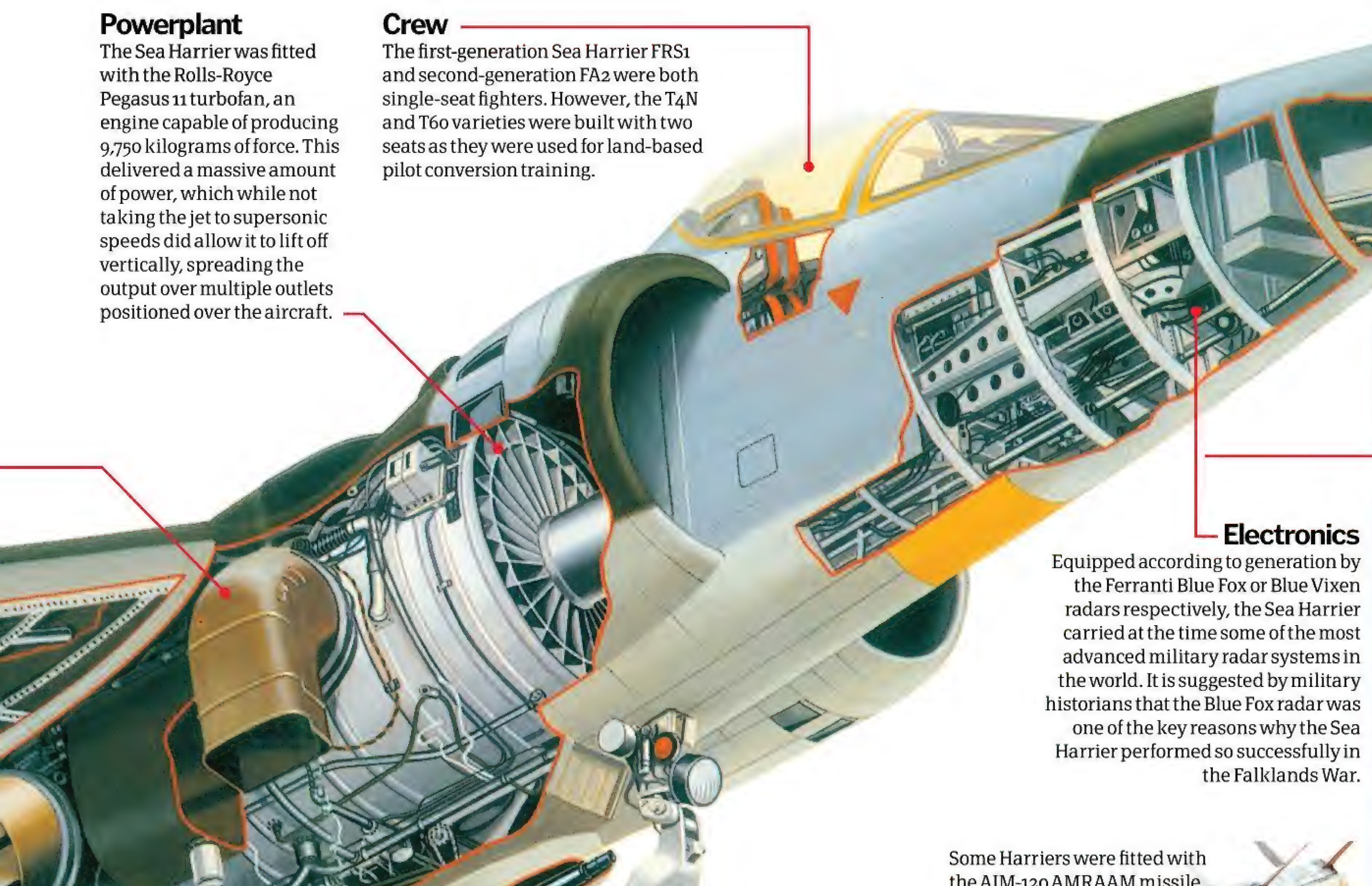
Post-colonial
2 The only other international operator of the Sea Harrier is actually India, who use their own FRS51 variant armed with R550 Magic air-to-air missiles.

Invincible
3 The first ever Sea Harrier confirmed as operational launched off the Invincible class aircraft carrier HMS Invincible in 1981, a purpose-designed VTOL/STOL carrier.

Vixen
4 The second-generation Sea Harrier, the FA2, featured the Blue Vixen radar, the predecessor that formed the basis of the system used in the Eurofighter Typhoon.

Forgetful
5 The second-generation Sea Harrier was also the first British aircraft to be armed with the US AIM-120 AMRAAM, a fire and forget high-explosive air-to-air missile.

DID YOU KNOW? During the Falklands conflict the Sea Harrier shot down 20 Argentine aircraft with no air-to-air losses



Powerplant
The Sea Harrier was fitted with the Rolls-Royce Pegasus 11 turbofan, an engine capable of producing 9,750 kilograms of force. This delivered a massive amount of power, which while not taking the jet to supersonic speeds did allow it to lift off vertically, spreading the output over multiple outlets positioned over the aircraft.

Crew
The first-generation Sea Harrier FRS1 and second-generation FA2 were both single-seat fighters. However, the T4N and T60 varieties were built with two seats as they were used for land-based pilot conversion training.

Electronics
Equipped according to generation by the Ferranti Blue Fox or Blue Vixen radars respectively, the Sea Harrier carried at the time some of the most advanced military radar systems in the world. It is suggested by military historians that the Blue Fox radar was one of the key reasons why the Sea Harrier performed so successfully in the Falklands War.

Some Harriers were fitted with the AIM-120 AMRAAM missile

Armament
As a strike fighter the Sea Harrier was equipped with a broad arsenal, ranging from conventional, unguided iron bombs – including WE.177 nuclear options – to rockets and laser-guided missiles such as the AIM-9 Sidewinder. The second generation FA2 was famously equipped with deadly AIM-120 AMRAAM air-to-air, fire and forget missiles.

The statistics...

Sea Harrier FA2

Crew: 1
Length: 14.2m
Wingspan: 7.6m
Height: 3.71m
Max take-off weight: 11,900kg
Powerplant: 1 x Rolls-Royce Pegasus turbofan (21,500lbf)
Max speed: 735mph
Combat radius: 1,000km
Max range: 3,600km
Max service ceiling: 16,000m
Guns: 2 x 30mm ADEN cannon pods (100 rounds per cannon)
Rockets: 72 SNEB 68mm rockets
Missiles: AIM-9 Sidewinder, AIM-120 AMRAAM, R550 Magic, ALARM anti-radiation missile, Martel missile, Sea Eagle anti-ship missile
Cost: $18 million

Degrees of power
Giving the Sea Harrier lift off

The real showpiece and reason for the lengthy success of the Sea Harrier was its utilisation of the Harrier's revolutionary Pegasus engine partnered with thrust vectoring nozzles. These nozzles could be rotated by the pilot through a 98.5 degree arc, from the conventional aft (horizontal) positioning as standard on aircraft, to straight down, allowing it to take off and land vertically as well as hover, to forward, allowing the Harrier to drift backwards. All nozzles were moved by a series of shafts and chain drives, which insured that they operated in unison (crucial for maintaining stability) and the angle and thrust was determined in-cockpit by the pilot.

This flexibility of control and placement meant that the Sea Harrier was highly manoeuvrable while in the air and could be landed and launched from almost anywhere.

The Sea Harrier's vectoring nozzle in aft position

"It was famed for its ability to pass the sound barrier, going supersonic in a shallow dive"

Sea Vixen

Sporting one of the most notable post-war aircraft designs, the de Havilland Sea Vixen was a fearsome all-weather jet fighter, capable of taking its pilots supersonic and delivering a titanic amount of next-generation firepower

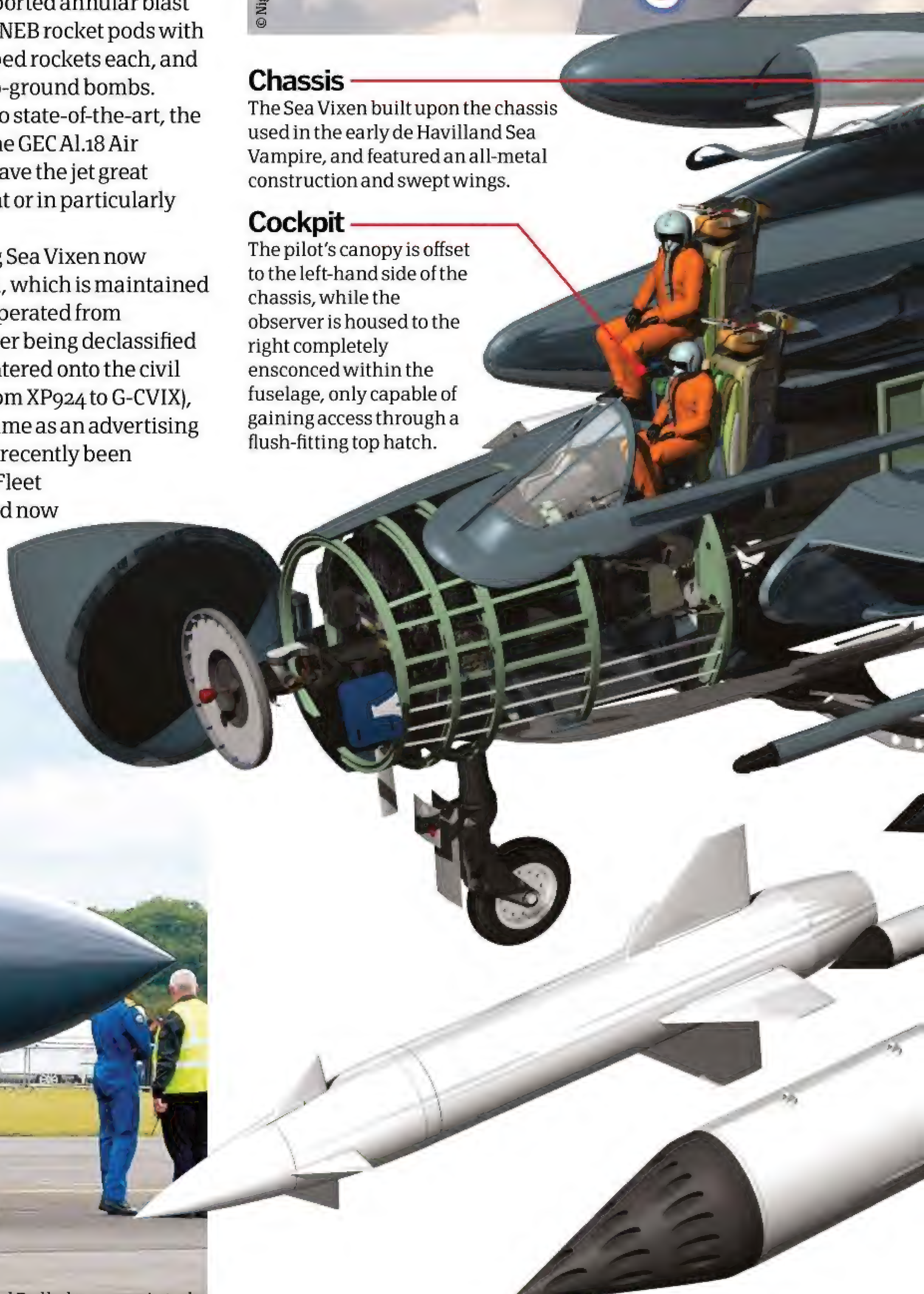
The first British fighter to be fitted purely with missiles, rockets and bombs – rather than the heavy calibre machine guns relied upon in WWI and WWII – the Sea Vixen was a first generation jet fighter employed by the Fleet Air Arm of the Royal Navy. It was famed for its ability to pass the sound barrier, going supersonic when in a shallow dive (hitting a top speed of 690mph) and saw action in multiple missions in the Middle East and Africa during the Sixties and Seventies.

Designed to be deployed from aircraft carriers as an all-weather fighter and high-speed reconnaissance jet, the Sea Vixen worked by partnering the reinforced twin-boom tail layout as seen on its predecessors the Sea Vampire and Sea Venom, with the colossal power generated by twin Rolls-Royce Avon 208 turbojet engines, each capable of delivering 7,500lb of thrust. This gave the Vixen massive speed, a range of 600 miles – the twin-boom layout allowed for more fuel tanks – and a flexibility to engage targets at sea, on land and in the air, as well as conduct lengthy patrols.

The armament of the Sea Vixen was revolutionary for the time. With six hardpoints (areas that weapons can be mounted on) capable of being fitted with a selection of Firestreak air-to-air missiles, which sported annular blast fragmentation warheads, SNEB rocket pods with 68 unguided explosive-tipped rockets each, and whopping 500-pound air-to-ground bombs. Detection of targets was also state-of-the-art, the Sea Vixen was fitted with the GEC Al.18 Air Interception radar, which gave the jet great strategic vision even at night or in particularly poor visibility conditions.

In 2015, only one working Sea Vixen now survives in the entire world, which is maintained by Naval Aviation Ltd and operated from Yeovilton, Great Britain. After being declassified as a military aircraft and entered onto the civil register (changing its tag from XP924 to G-CVIX), the aircraft was used for a time as an advertising vehicle for Red Bull but has recently been repainted with its original Fleet Air Arm 899 NAS colours and now flies regularly as part of demonstrations and air shows across the United Kingdom.

© Nigel Ish



Chassis
The Sea Vixen built upon the chassis used in the early de Havilland Sea Vampire, and featured an all-metal construction and swept wings.

Cockpit
The pilot's canopy is offset to the left-hand side of the chassis, while the observer is housed to the right completely ensconced within the fuselage, only capable of gaining access through a flush-fitting top hatch.

The Red Bull plane repainted in its original livery

5 TOP FACTS SEA VIXEN

Disaster
1 On 6 September 1952, a prototype Sea Vixen disintegrated in mid-air at the Farnborough Airshow while attempting to break the sound barrier, killing 31 people.

Breaker
2 One of the crew killed at the Farnborough Airshow was John Derry, the first British person to exceed the speed of sound in a de Havilland DH 108 in September 1948.

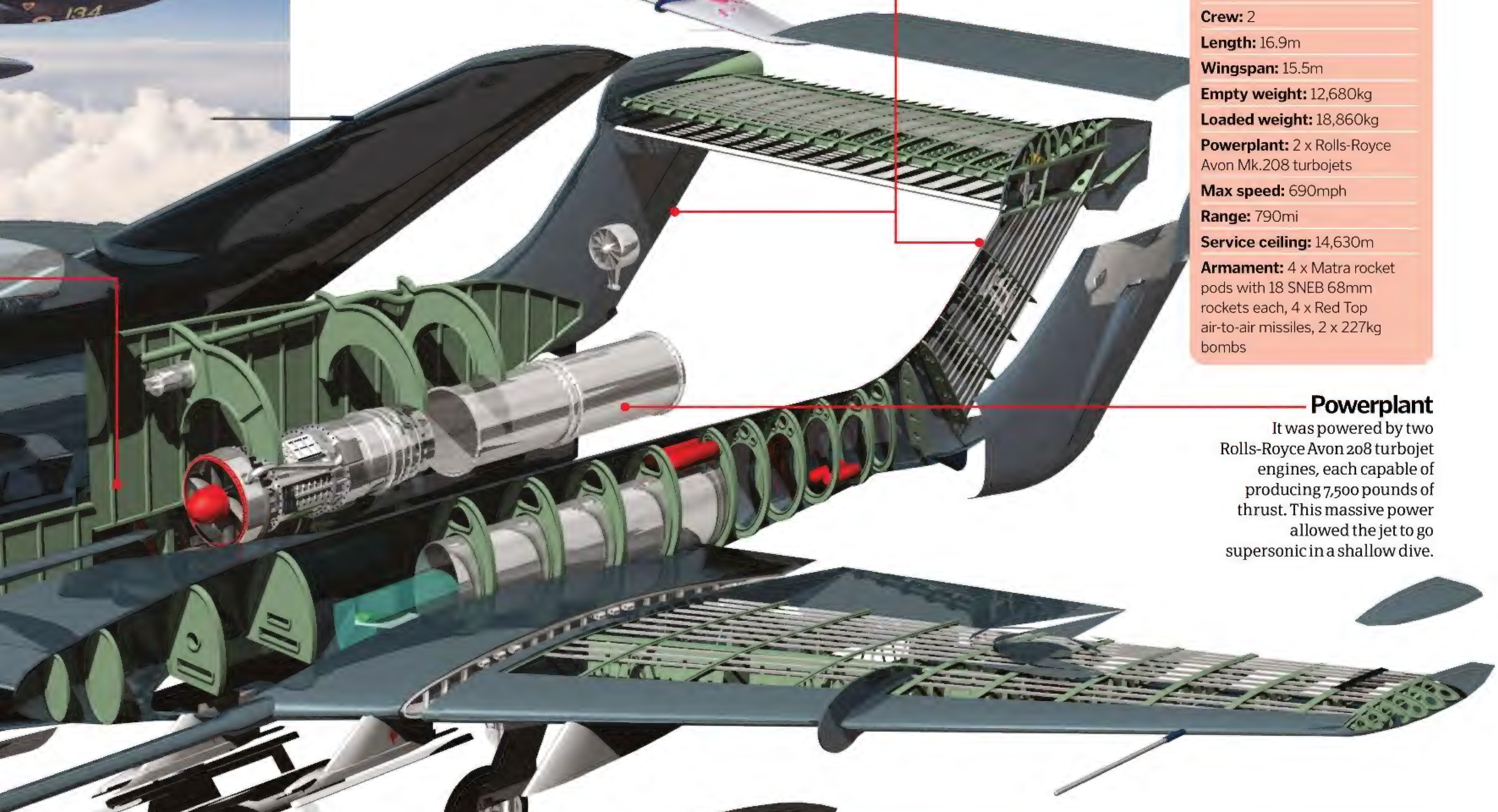
Home
3 The only remaining Sea Vixen capable of flight was kept at Bournemouth International Airport in Dorset, Britain. Until an accident occurred on the runway in 2014

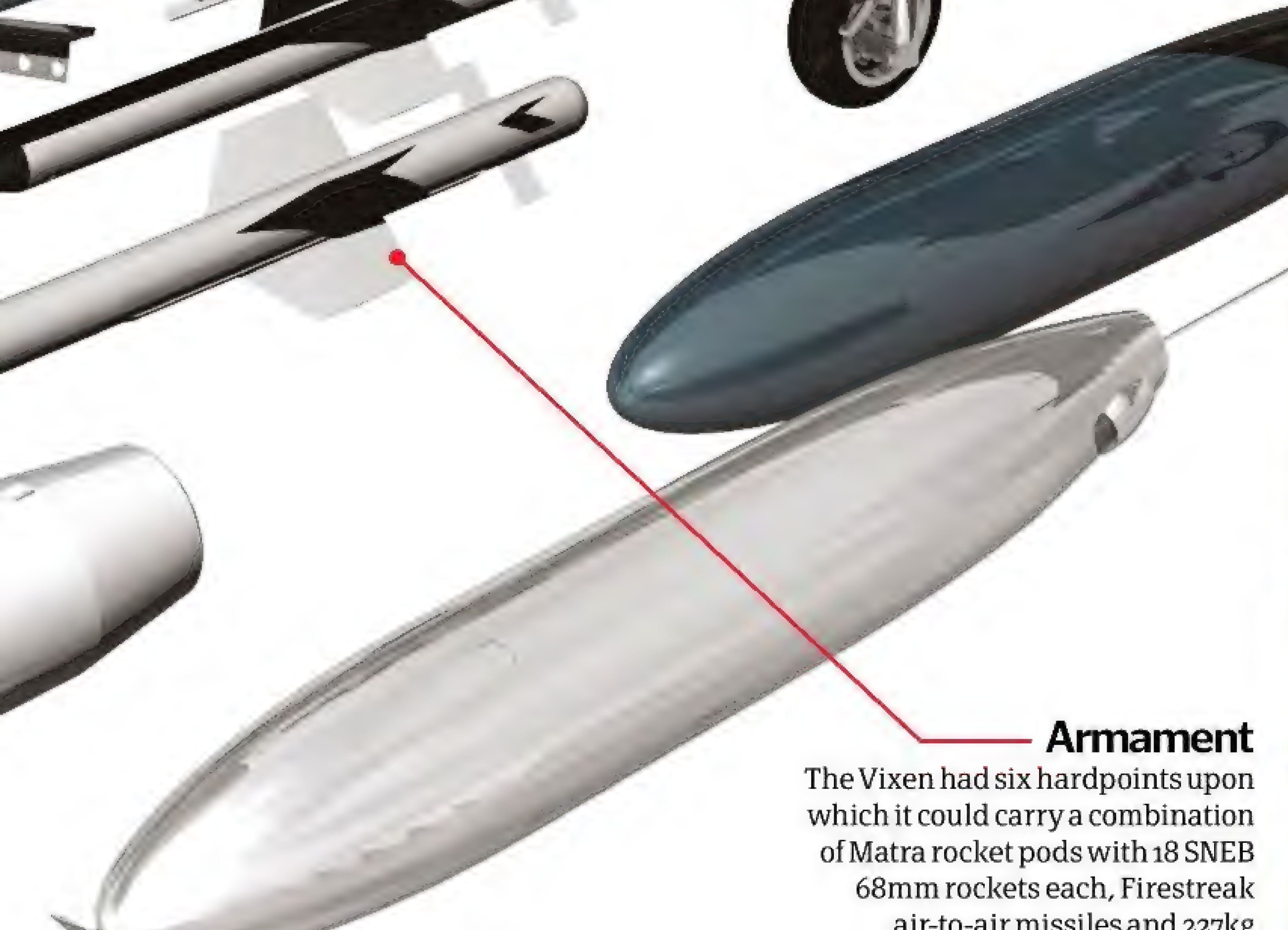
Merger
4 The Sea Vixen was produced by the de Havilland company, but post merger with the Hawker Siddeley aerospace group, it was renamed the Hawker Siddeley Sea Vixen.

Vintage
5 De Havilland Aviation is a company that specialises in acquiring and reconditioning most military aircraft. You can find out more at **www.dehavillandaviation.com**

DID YOU KNOW? *There is only one fully functioning Sea Vixen left in the world*

The Sea Vixen could reach speeds of up to 690mph





Twin-boom
Another similarity shared with the Sea Vampire was the Sea Vixen's twin boom tail layout, which aided strength and rigidity when travelling at sub-sonic and near sub-sonic speeds.

Powerplant
It was powered by two Rolls-Royce Avon 208 turbojet engines, each capable of producing 7,500 pounds of thrust. This massive power allowed the jet to go supersonic in a shallow dive.

Armament
The Vixen had six hardpoints upon which it could carry a combination of Matra rocket pods with 18 SNEB 68mm rockets each, Firestreak air-to-air missiles and 227kg high-explosive bombs.

The statistics...

© Tony Hisgett

Sea Vixen

Crew: 2
Length: 16.9m
Wingspan: 15.5m
Empty weight: 12,680kg
Loaded weight: 18,860kg
Powerplant: 2 x Rolls-Royce Avon Mk.208 turbojets
Max speed: 690mph
Range: 790mi
Service ceiling: 14,630m
Armament: 4 x Matra rocket pods with 18 SNEB 68mm rockets each, 4 x Red Top air-to-air missiles, 2 x 227kg bombs

A Sea Vixen with Red Bull advertising

> "Since the first flight the Lynx has been continually upgraded and developed"

Westland Lynx

A record breaker and for over 40 years – can anything beat the Lynx?

The Westland Lynx forms the backbone of the British Army and Navy helicopter forces. Entering military service in 1978, it had already set world speed records during testing. Introduced as a utility helicopter in 1971, the Lynx is a twin gas turbine-powered, two-pilot aircraft, with advanced control systems, a four-blade, semi-rigid rotor and, thanks to the fundamental stability and unrivalled agility of the basic airframe, it has performed in almost every role imaginable.

From troop transport, armed escort and anti-tank warfare with the Army Air Corps, to anti-submarine warfare and maritime attack with the Fleet Air Arm, and in many similar roles across the globe, the Lynx is used by the militaries of over a dozen countries worldwide.

This helicopter is used as an airborne command post, a fire support platform, as well as for search and rescue, casualty evacuation, plus many specialist roles including anti-pirate and border patrol. The British Army and Navy also have display teams that use the exceptional agility of the Lynx to amaze the crowds at air shows.

Since its first flight, over four decades ago, the Lynx has been continually upgraded and developed, ensuring it's always at the forefront of technology, as demonstrated by the most current variant, the Super Lynx. Army models kept the traditional landing 'skids' until only recently, when they adopted the tricycle-wheeled undercarriage used by the Navy to aid ground handling.

Improvements in navigation, communication and radar systems in Navy derivatives have ensured that British helicopter capability at sea is world leading, while Army versions have similarly demonstrated their ability to evolve with the changing requirements of modern warfare.

The latest variants are excelling on the battlefield, using state-of-the-art weapons and tactics including night-vision-assisted operations. The next generation of Lynx (the Wildcat) is currently undergoing flight testing on land and sea, ensuring many years of continued service.

Lynx AH.9 teardown

The AH.9 variant of the Lynx is used exclusively by the British Army, primarily as a utility vehicle

The statistics...

Westland Lynx AH.9

Length: 15.2m (50ft)
Rotor diameter: 12.8m (42ft)
Height: 3.8m (12.4ft)
Disc area: 128.7m² (1,385ft²)
Empty weight: 3,291kg (7,255lb)
Max takeoff weight: 5,330kg (11,750lb)
Powerplant: 2 x Rolls-Royce Gem 41-1 turboshaft, 835kW (1,120shp) each
Max speed: 324km/h (201mph)
Range: 528km (328mi)

5 TOP FACTS
WESTLAND LYNX

Unbeatable record?
1 The world helicopter speed record set by G-LYNX still stands over 25 years later. With the latest fast rotorcraft moving away from eligible designs, G-LYNX's record may never be broken.

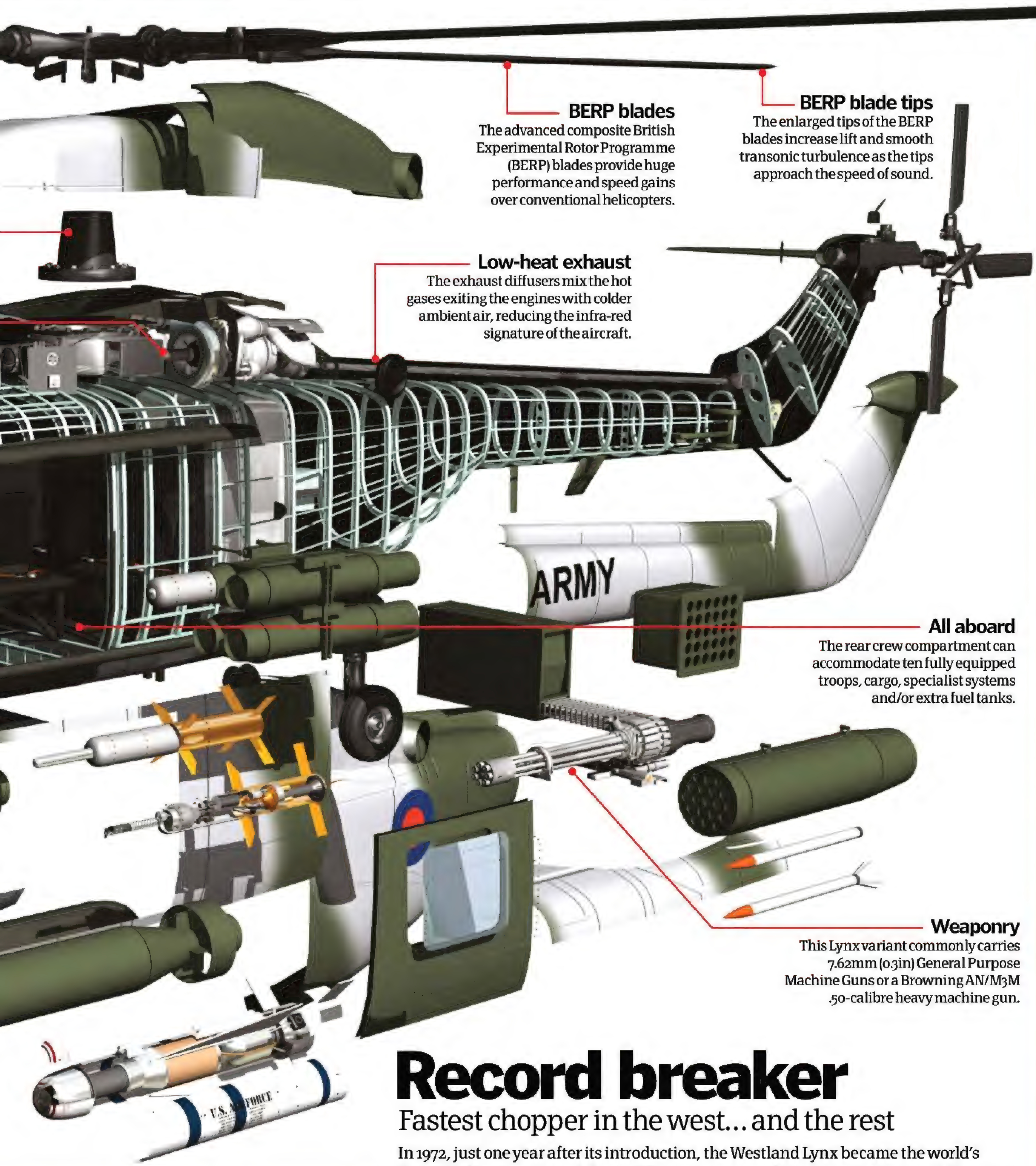
War veteran
2 The Lynx has proven capabilities in many combat environments, including disabling the Argentine submarine Santa Fe during the Falklands campaign, and sinking several Iraqi ships in the Gulf Wars.

Blow me down
3 Naval versions of the Lynx have the ability to angle the main rotor blades downwards to generate negative lift, pushing the aircraft onto the deck of a ship after landing.

More speed?
4 An even faster variant of the Lynx was proposed but never built. It would not have qualified for a world speed record, though, as it had aeroplane-like wings beneath the rotor.

Super-strong
5 The key component in the Lynx rotor is a solid titanium hub around which everything spins. This provides the strength needed for both high-speed and high-agility manoeuvres.

DID YOU KNOW? The Lynx is one of the few helicopters in the world that can perform advanced aerobatics, including loops



Record breaker
Fastest chopper in the west… and the rest

In 1972, just one year after its introduction, the Westland Lynx became the world's fastest helicopter when airframe XX153 set a new world speed record over 15-kilometre (9.3-mile) and 25-kilometre (15.5-mile) straight courses by flying at an average 321.7 kilometres (199.9 miles) per hour. In 1978 a heavily modified Russian Mil Mi-24 'Hind' increased this to 368.4 kilometres (228.9 miles) per hour. With Westland under political and commercial pressure, it was decided that an attempt would be made to reclaim the record. Westland re-registered Lynx airframe ZB500 as G-LYNX, and began a programme of extensive modification. More powerful Rolls-Royce Gem 60 gas turbines were fitted, along with a water-methanol injection system, but the biggest performance contribution came from the British Experimental Rotor Programme (BERP). On 8 August 1986, these advanced rotor blades carried G-LYNX pilot Trevor Egginton and his flight engineer Derek Clews to the world record speed of 400.9 kilometres (249.1 miles) per hour, which still stands to this day.


The Lynx Mark 3 shares many of the same features as the record-holding G-LYNX, such as BERP blades and Rolls-Royce Gem engines

© Crown Copyright

Top trumps:
MILITARY CHOPPERS


© AgustaWestland

WESTLAND LYNX AH.9
The Lynx is the smallest and lightest aircraft of the three in this roundup, which allows it to operate from small ships. The Lynx can carry more troops and is far more agile than its larger counterparts, but has less power so cannot carry as high a payload or as many weapons.


© US Navy

SIKORSKY SH-60 SEAHAWK
The Seahawk has a huge range advantage over its competitors – almost twice that of the Hind. The common parts it shares with the other aircraft in the Blackhawk family make maintenance and repair highly cost effective. However, it cannot operate from small ship decks, and is not particularly agile.


© BrokenSphere

MIL MI-24 HIND
The Hind is heavily armoured, heavily armed, extremely fast and very powerful. It is not used by the Navy due to its limited range, and its size means it is not very agile. Despite the variety of fearsome weapons that it can carry on its hardpoints, the Hind has often lacked a reliable anti-armour capability.

© Alex Pang

Strategic bombers

Dedicated bombing aircraft act as damage-dealing workhorses, engaging enemy targets 24/7 regardless of weather conditions and the hazardous theatre of war. We take to the skies for a closer look at some of its key players

Deployed to support ground troops in the Libyan civil war, the B-1B Lancer packs a powerful payload

© USAF

© USAF

The battlefield has changed. Now, more than ever before, the theatre of war is in flux, rebuilding itself minute-by-minute, breaking down the conventional barriers of geography, geometry and time. Weapons systems are co-evolving along with defence systems at a ferocious rate, fuelled by the continued, perpetual rage of a segregated planet. The relationship between organic and inorganic matter is becoming fused, co-dependent and augmented, in order to generate the versatility demanded when fighting in the 21st Century. Fluidity and reaction speed is now paramount, for if you have the inability to engage immediately on a global scale, the parameters shift and the chance dissipates.

Strategic bombers are positioned at the leading edge of this technological and logistical war, built to offer the range, payload, durability and speed to engage a hostile target quickly and efficiently, no matter their location or levels of defence. Installed with the most cutting-edge technology and weapons systems available these machines excel in delivering their human operator near-omnipresent power. They include missiles that can transcend the speed of sound three times over, bombs that are guided by invisible, omnipresent satellite links to their targets, and nuclear warheads over ten times the power of that which despoiled Hiroshima. Strategic bombers are also capable of remaining airborne for days, protected by their insane speed and large weapons basket (the range in which they can launch weapons at a target without themselves being engaged).

5 TOP FACTS Bombers

Fortress
1 The B-1 Lancer was originally conceived in the late-Sixties as a supersonic bomber with the range and payload to replace the famous Boeing B-52 Stratofortress.

Father
2 According to Russian government sources, it was a Tu-160 that dropped the 'Father of all bombs'. The government commented: 'all that's alive merely evaporates'.

Iraq
3 The B-1 Lancer was one of the most used aircraft during the Iraq war. One of its most notable missions was an unsuccessful attempt to kill Saddam Hussein.

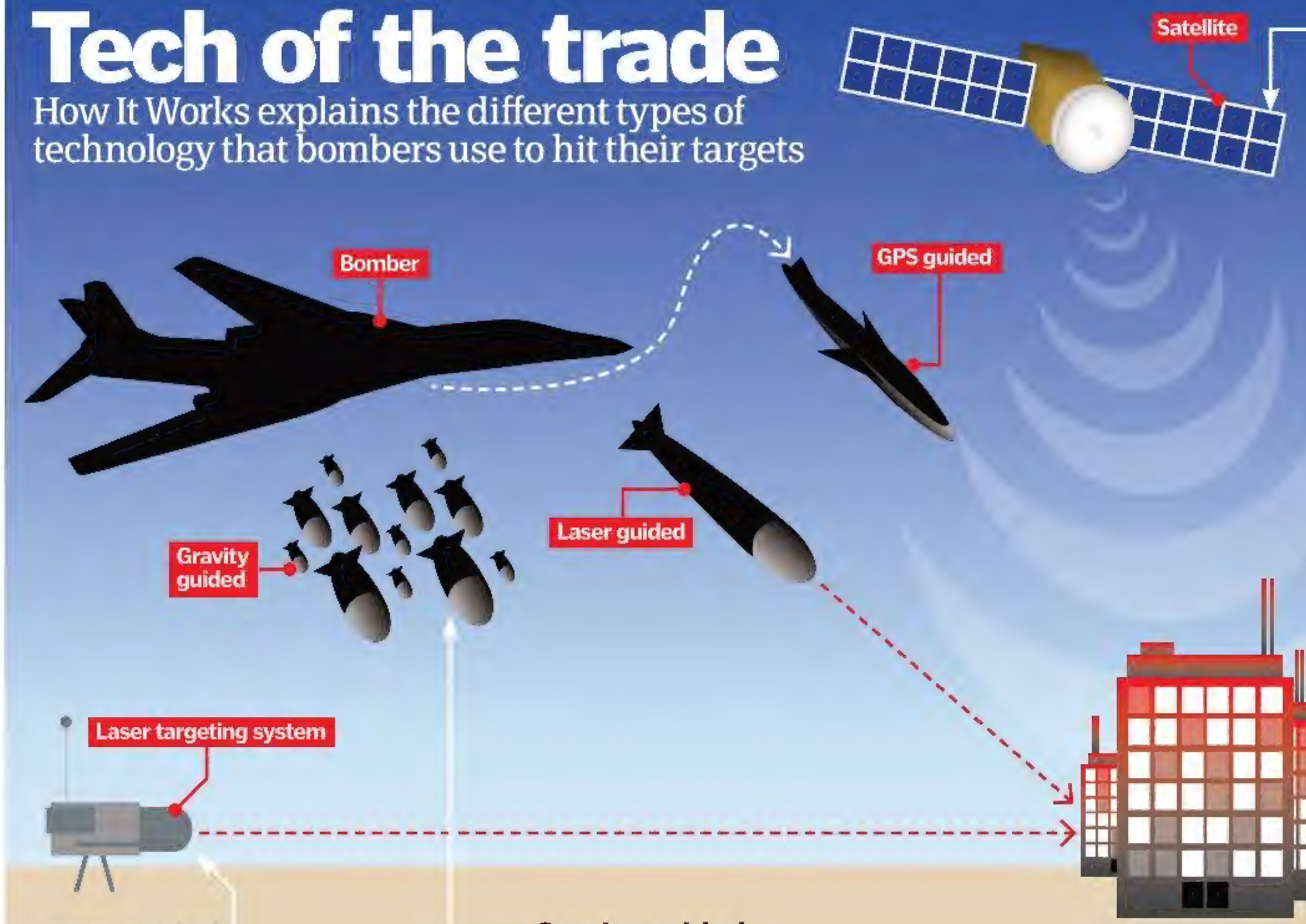
Swan
4 Russian pilots train to fly the Tu-160 in a Tu-22M aircraft. When they qualify, they can adopt its nickname 'White Swan' (due to its white finish and manoeuvrability).

Etymology
5 The etymology of 'bomb' comes from the French 'bombe', which comes from the Italian 'bomba', which comes from the Latin 'bombus', which stems from Ancient Greek.

DID YOU KNOW? A single B-1B Lancer costs $283 million to produce

Tech of the trade

How It Works explains the different types of technology that bombers use to hit their targets



GPS-guided
One of the most modern guidance systems, GPS-guided missiles allow targets to be engaged accurately. The system uses an Inertial Navigation System (INS) with a link to Earth-orbiting satellites that relay and feed back positional data to the missile. With GPS enabled, JDAM missiles have a Circular Error Probable (a measure of accuracy) of just under 13m, however if jammed and under INS guidance only, that is more than doubled to 30m.

Laser-guided
Laser-guided systems rely on targets to be 'lit up' with a Laser Target Designator (LTD) system. Usually ground-based, they involve a laser designator being pointed at target. The missile's infrared seeking unit locates the designation and adjusts its trajectory.

Gravity guided
Bombs are dropped free-fall, relying on gravity and aircraft co-ordinates to strike. Due to their relative inaccuracy, gravity-guided bombs tend to be released in clusters to maximise the chance of a successful strike. Dependent on aircraft speed and altitude, these bombs can be fitted with various tails and retarders to speed up/slow down fall time.

A B-1B taking off at the Royal International Air Tattoo. Note the firing General Electric F101-GE-102 augmented turbofans

The B-1 is capable of being refuelled during flight for an extended patrol and bombing runs

© USAF

The statistics...

B-1B Lancer

Crew: 4
Length: 44.5m (146ft)
Wingspan: 41.8m (137ft)
Height: 10.4m (34ft)
Loaded weight: 148,000kg (326,000lb)
Powerplant: 4 x general electric F101-GE-102 augmented turbofans
Max speed: Mach 1.25 (830mph/1,340kmh)
Range: 11,998km (7,456 miles)
Max altitude: 18,000m (60,000ft)
Hardpoints: 9 (6 external, 3 internal)

The two current foremost examples of these bombers are the US B-1B Lancer and the Russian Tupolev Tu-160. These were designed concurrently to be machines that could, on demand, travel long distances quickly, slip under early-warning radar and engage military targets with smart munitions – bombs that could be launched from hundreds or thousands of miles out and guided to their target by internal inertial navigation units and auxiliary information delivery systems. These strategic bombers, packing gravity, laser and GPS-guided munitions (see 'Tech of the trade' boxout) render anti-aircraft gun placements useless, and avoid surface-to-air missiles by flying at altitudes northwards of 60,000 feet.

The B-1B Lancer is built around a blended wing body configuration, with variable-sweep wings, four turbofan engines and triangular fin control composite surfaces. Its wings can be varied by the pilot between 15 to 67.5 degrees, with the former being used for takeoff and landing as well as high-altitude cruising, and the latter being used for high subsonic and supersonic flight. Stability is ensured – a problem due to its large size and weight – by triangular fin control canards located by the B-1's nose. These are

WEAPONS OF WAR
B-1B Lancer

© Broken Sphere

MK-82
A low-drag, general-purpose, unguided bomb. It is a stock munition for a variety of US aircraft, including the B-1B Lancer, which can carry northwards of 84 units. The MK-82 weighs 500 pounds and measures 222cm (87.4in) long and 27cm (10.75in) in diameter. Each unit has a 192lb filling of tritonal – 80 per cent TNT, 20 per cent aluminium powder – which can be fitted with fin kits, fuses and retarders to suit each mission.

©Damon Moritz-USN

AGM-154
A medium-range launch-and-leave missile, the AGM-154 allows bombing aircraft to engage defended targets from outside the range of conventional anti-air weaponry. The missile, which measures 406cm (160in) long by 33cm (13in) in diameter, is guided by a Global Positioning System of satellites with an internal Inertial Navigation System. This twin system allows for enhanced accuracy and release range.

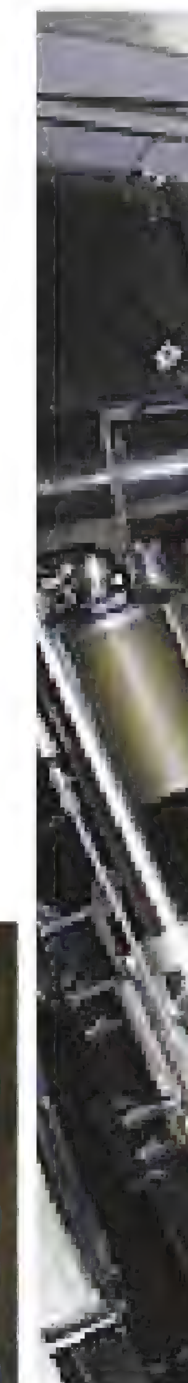
GBU-39
The GBU-39 is a small-diameter bomb weighing little more than 250 pounds that, dependent on specification, can be guided to a target via a GPS-aided inertial navigation system (as with the AGM-154), or by a thermal seeker with integrated auto target recognition. The thermal seeker works by tracking the electromagnetic radiation of a target with an IR sensor (infrared), before visibly zeroing in on the heat signature once launched.

"The Tupolev Tu-160 is larger and heavier than the B-1"

controlled by the Lancer's Structural Mode Control System (SMCS), which automatically rotates the canards to counteract turbulence. In addition, to aid the minimisation of its radar cross section (RCS), the B-1 is installed with serpentine air intake ducts and fixed intake ramps. These, while limiting its top speedm deflect and shield radar emissions from the highly reflective engine compressor blades. This technology, in partnership with the use of radar-absorbent material in its airframe and skin, grant the B-1 a RCS 1/50th of that of the equally massive B-52 Stratofortress.

The Tupolev Tu-160, in contrast, is larger and heavier than the B-1, however it shares many of the same features and design choices. First, the aircraft sports a blended wing profile with sweep-enabled wings that can be swept by the pilot between 20 and 65 degrees. It is also powered by four Kuznetsov NK-321 afterburning turbofan engines, the most powerful array fitted to any combat aircraft. These, in partnership with variable air intakes, grant it a B-1 topping max speed of Mach 2.05 (1,380mph), although its radar signature is larger as a result. Due to its larger size, the 160 also has a greater weapons load capacity than the B-1, with twin internal rotary launchers capable of holding and launching 40,000kg of munitions. In addition, nuclear and conventional armaments can be carried (see the 'Weapons of war – Tu-160' boxout) dependent on mission parameters. Finally, as with the B-1, the Tu-160 is fitted with a probe and drogue in-flight refuelling system, allowing it to remain airborne for extensive periods.

Both of these aircraft have demonstrated their awesome ability since their introduction to the skies, with numerous sorties undertaken and many notable records broken. Most recently the USAF deployed a series of B-1s as part of Operation Odyssey Dawn, the international military operation in Libya, to prevent Muammar Gaddafi's forces from bombing rebel forces, striking a multitude of undisclosed military targets.



WEAPONS OF WAR
Tu-160

Kh-55
A Soviet/Russian air-launched cruise missile capable of carrying a conventional or nuclear warhead, the Kh-55 is the primary missile system of the Tu-160. It has a range of 3,000km and a top speed of Mach 0.78, while thanks to its Inertial Navigation System with a Doppler radar mapping service, has a strike accuracy of within 9m. To achieve its range the Kh-55 is powered by an R95-300 turbofan engine, activated along with swept wings once launched. Missiles are stored in a rotary launcher, which rotates missiles like a six-shooter's bullet chamber until in optimal position.

Kh-15
The Kh-15 is a short-to-medium range missile that can be equipped with a nuclear or conventional warhead. 4.5m (15ft) long by 5.5m (17.9 ft) in diameter and with a range of 300km (186 miles), the missile is guided by inertial navigation, active radar or anti-radiation – the latter a system that detects and homes in on an enemy's radio emissions. Central to the Kh-15's design is its post-launch velocity accumulation flight path, climbing to 130,000ft before diving at a speed of Mach 5 (almost 4,000mph) onto its target.

Tu-160
The world's largest variable-sweep aircraft, the Tu-160 is a supersonic strategic missile carrier like no other

Electronics
In terms of electronics, the 160 utilises a Obzor-K attack radar in a dielectric radome, a Sopka terrain-following radar and electro-optical bombsight.

A Tu-160 is exhibited to the general public during a Russian airshow

© Yevgeny Pashnin

Engines
The four Kuznetsov NK-231 engines of the 160 are ferocious, delivering 24,948 kilograms of thrust each in maximum afterburner configuration.

Munitions
The Tu-160 can carry 40,000 kilograms of munitions, with two rotary launchers capable of stowing conventional or nuclear missiles.

The Tu-160 has the heaviest take-off weight of any combat aircraft

© Sergey Krivchikov-Russian AviaPhoto Team

President of Russia Vladimir Putin (above) sits in the cockpit of a Tu-160

Cockpit
The Tu-160 is operated by a crew of four, with a pilot, co-pilot, weapons systems operator and defensive systems operator on board each sortie.

Wings
The Tu-160 features variable geometry wings, with sweep selectable from 20 to 65 degrees. It also employs a blended wing profile.

The statistics...

© Presidential Press and Information Office

Tu-160

Crew: 4
Length: 54.10m (177ft)
Wingspan: 55.70m (189ft)
Height: 13.10m (43ft)
Loaded weight: 267,600kg (589,950lb)
Powerplant: 4 x Samara NK-321 turbofans
Max speed: Mach 2.05 (1,380mph/2,220kmh)
Range: 12,300km (7,643 miles)
Max altitude: 15,000m (49,200ft)
Hardpoints: 4

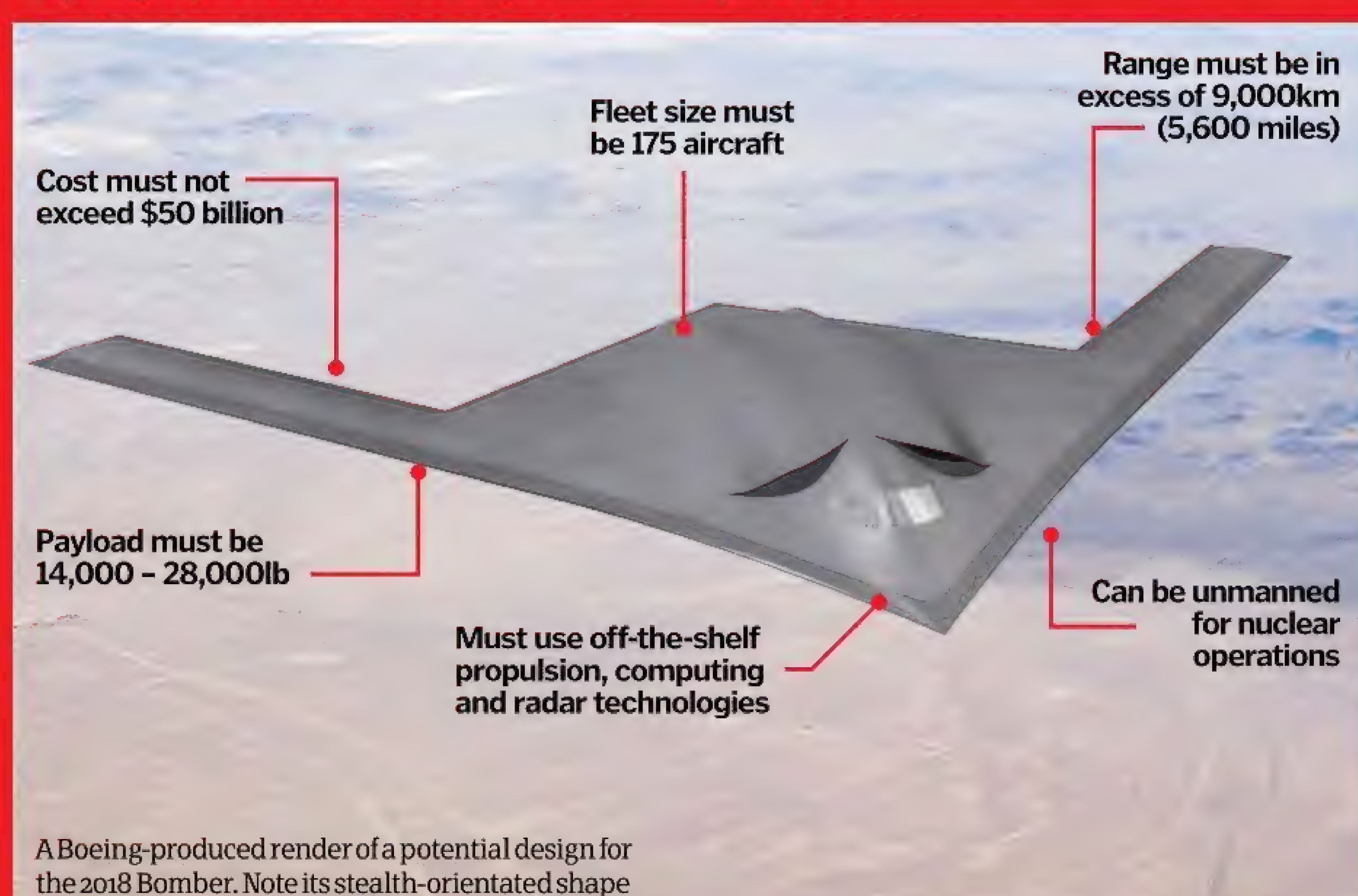
A series of Mk-82 bombs explode in quick succession during a test bombing run

A collection of laser-guided bombs connect with Raynham island, Queensland, Australia

Bombers of the future

New machines to be ready for 2018

Despite current bombers' advanced technology and weapons, the US Air Force is now developing its next-generation bomber, scheduled to enter service by 2018. Codenamed the '2018 Bomber', the new system is poised to harness the stealth-orientated strike capabilities of the F-35 fighter jet but extend them into an aircraft with long-range operability. With a design brief that the new bomber must be capable of strategic bombing, tactical bombing and prompt global strike roles, as well as having the ability to carry nuclear weapons, a host of companies including Lockheed Martin, Boeing and Northrop Grumman are working towards a prototype being delivered for 2016. See below for the 2018's design goals as of January 2011:



A Boeing-produced render of a potential design for the 2018 Bomber. Note its stealth-orientated shape

© Boeing

ARMED & DANGEROUS
ATTACK HELICOPTERS

THE DEADLY GUNSHIPS ELIMINATING THE ENEMY FROM ABOVE

DID YOU KNOW? A Chinook is big enough for two Land Rovers to fit inside it

The AH-64 Apache is one of the most iconic and successful attack helicopters

"Many new gunships were constructed as the Cold War escalated"

The V-280 Valor will attempt to make attack helicopters faster and stronger than ever before

The modern attack helicopter is the complete military machine. Cutting through the air with titanium blades, loaded up with missiles and a cockpit full of advanced technology; they are true terrors of the sky. A tank's worst nightmare, the rise of attack helicopters has revolutionised the battlefield.

The idea of rotary wing military aircraft was first toyed with during the early years of World War II but it wasn't until 1942 that they reached prominence. That year the US War Department proposed a new idea. It was called 'organic Army aviation' and, separate from the Air Corps, it was tasked with developing helicopters. Various new designs, including the revolutionary Sikorsky R-4, were created but it took until the Korean War for helicopters to really take off. Infantry and cargo could now be ferried in and out of battle rapidly and invasion forces could engage the enemy much more effectively from the air. Helicopters were integral to US operations in the rough terrain of Korea and by the time of the Vietnam War, the iconic Bell UH-1 Iroquois was used extensively. The 'Huey' ushered in a new era of air cavalry, as helicopter weaponry became more sophisticated.

Military helicopters were also designed to serve in a purely offensive capacity and the attack helicopter was born. Many new gunships were constructed as the Cold War escalated. These included the American Piasecki H-21 and Bell AH-1 Cobra and the Russian Mil Mi-24. In 1986, the Boeing AH-64 Apache emerged as a template that other armed forces tried to replicate, and helped bring an end to the dominance of tanks on the battlefield. As more breeds of attack helicopter took to the skies, it became clear that these versatile vehicles could assist the military in many ways. This led to the advent of dual and multi-role helicopters.

In recent years, attack helicopters have been equipped with ever more advanced systems that have improved efficiency, aerodynamics and performance. The array of tech on offer is truly astonishing, but there is still room for further progress. Join us as we examine what's on offer for the future of the world's best attack choppers.

TYPES OF MILITARY HELICOPTER

Choppers are an essential part of modern warfare, from reconnaissance to attack

Attack
Commonly known as gunships, attack helicopters come armed with a multitude of rockets, missiles and chain guns. The AH-64 Apache specialises in disabling tanks.

Transport
Supplies and troops can be quickly whisked in and out of war zones. A popular design is the CH-47 Chinook which has a primary role in heavy troop and supply transport.

Multi-role
State-of-the-art navigation and communication systems allow helicopters to assist almost any mission. Their roles range from observation to search and rescue.

Maritime
Maritime helicopters provide invaluable aerial support out at sea. The Sikorsky SH-60 Seahawk takes off from aircraft carriers and frigates and can take down submarines with its MK 54 torpedoes.

Scout
Helicopters like the Aérospatiale Gazelle are used to investigate unknown terrain. They are sent ahead of the front line to inspect what lies in wait for the ground forces.

THE TIGER

The all-action attack gunship that is a key player in modern aerial warfare

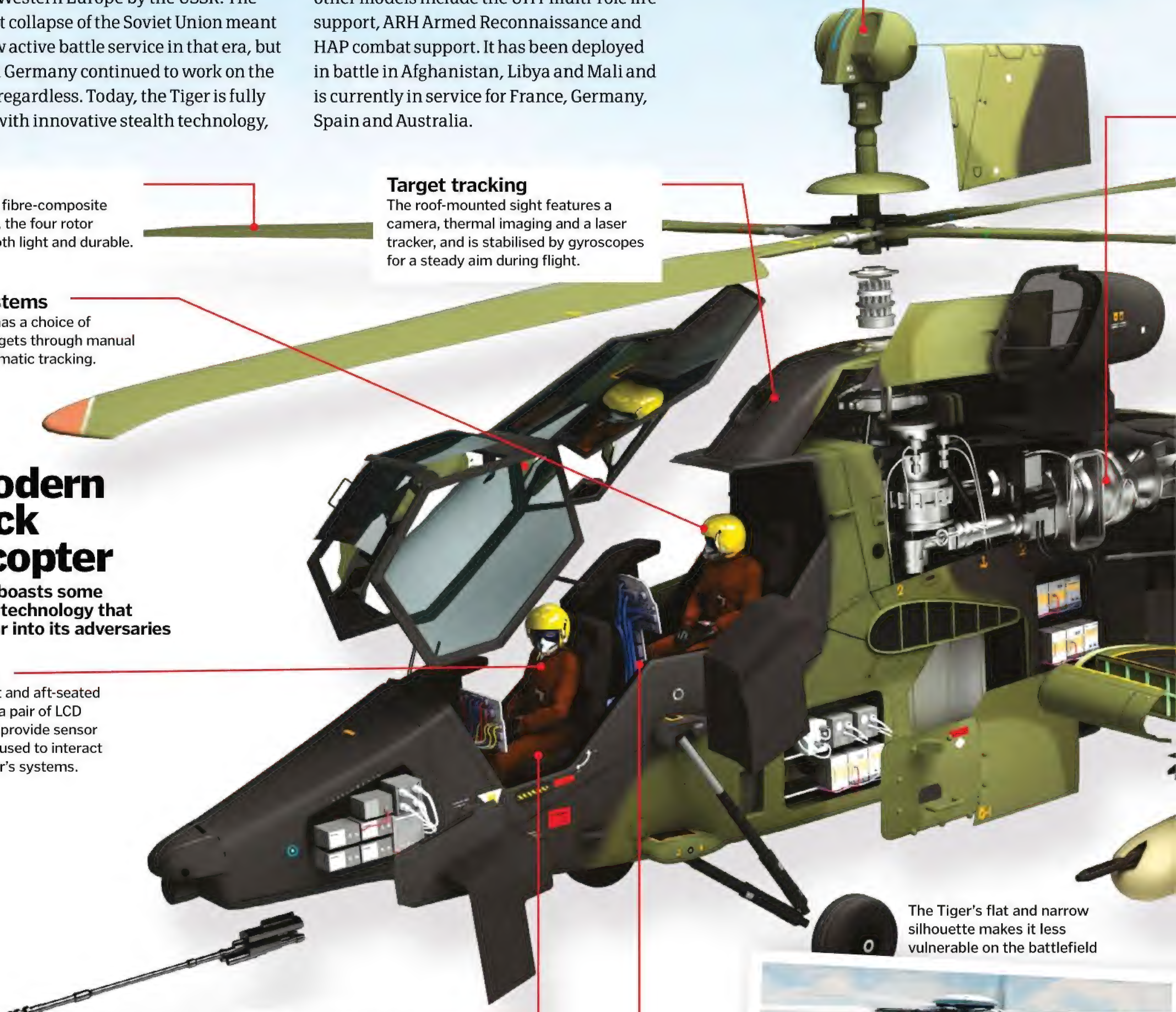
A heavy-hitting, relentless attack dog, the Airbus Helicopters Tiger has both the armament and performance capabilities to dominate the battlefield. During the Cold War, it was developed in order to respond to any potential attacks on Western Europe by the USSR. The subsequent collapse of the Soviet Union meant it never saw active battle service in that era, but France and Germany continued to work on the helicopter regardless. Today, the Tiger is fully equipped with innovative stealth technology, highly accurate GPS systems, and electronic countermeasures. It specialises in anti-tank missions but the Tiger's flexibility means that it can handle a variety of roles. The image below is of an HAD combat helicopter but other models include the UHT multi-role fire support, ARH Armed Reconnaissance and HAP combat support. It has been deployed in battle in Afghanistan, Libya and Mali and is currently in service for France, Germany, Spain and Australia.

Mast-mounted sight
Electronics company SAGEM supply the Osiris sight that acts as a forward looking infrared (FLIR) camera and laser rangefinder.

Blades
Made from a fibre-composite construction, the four rotor blades are both light and durable.

Target tracking
The roof-mounted sight features a camera, thermal imaging and a laser tracker, and is stabilised by gyroscopes for a steady aim during flight.

Firing systems
The gunner has a choice of acquiring targets through manual sight or automatic tracking.



A modern attack helicopter

The Tiger boasts some incredible technology that strikes fear into its adversaries

Interface
Both the pilot and aft-seated gunner have a pair of LCD displays that provide sensor data and are used to interact with the Tiger's systems.

Advanced cockpit
The pilot is assisted by an automatic flight control system that lessens the workload during long, strenuous flights and adverse weather conditions.

Cockpit
The Tiger's tandem cockpit allows the pilot and the aft-seat gunner to switch roles if needed, as both have access to the flight controls and weapon systems.

"The fuel tanks are self-sealing and explosion suppressive"

The Tiger's flat and narrow silhouette makes it less vulnerable on the battlefield

An AH-64D fires its flares as a countermeasure against infrared missile seekers

AH-64D APACHE LONGBOW

An iconic gunship that's still a capable attack chopper

The AH-64D Apache Longbow gunship is arguably the most famous multi-mission attack helicopter of the modern age. Over the past 19 years of service, it has proven itself both combat-ready and reliable in numerous theatres of conflict.

The AH-64D was upgraded in 2008 to include increased digitisation, a joint tactical radio system, enhanced engines and drive systems, the capability to control UAVs (unmanned aerial vehicles) – which were used extensively in the Iraq and Afghanistan wars – along with improved landing gear. Currently, the Apache AH-64D Longbow is operated by the US, Egypt, Greece, Israel, Japan, Kuwait, the Netherlands, China, Singapore and the United Arab Emirates, with many other countries operating older Apache variants.

1. T700-GE-701C engines
The turboshaft engines allow the AH-64D Longbow to reach a cruise speed of 284km/h.

2. Automatic cannon
The 30mm automatic cannon is capable of firing large, highly incendiary rounds.

3. Hellfire missiles
These laser-guided missiles are effective at taking down enemy armour and structures.

4. Explosive rockets
Fast firing 70mm rockets allow the Apache to support ground troops in any assault on enemy soldiers, strongholds or vehicles.

5. Cockpit
With room for two, the Apache's cockpit allows excellent battlefield visibility with wide viewing angles.

6. Composite rotor blades
A composite four-blade main rotor allows for increased payload, climb rate and cruise speed over earlier variants.

7. Fuselage
Designed for manoeuvrability and stealth, the fuselage is painted in camouflaged colours.

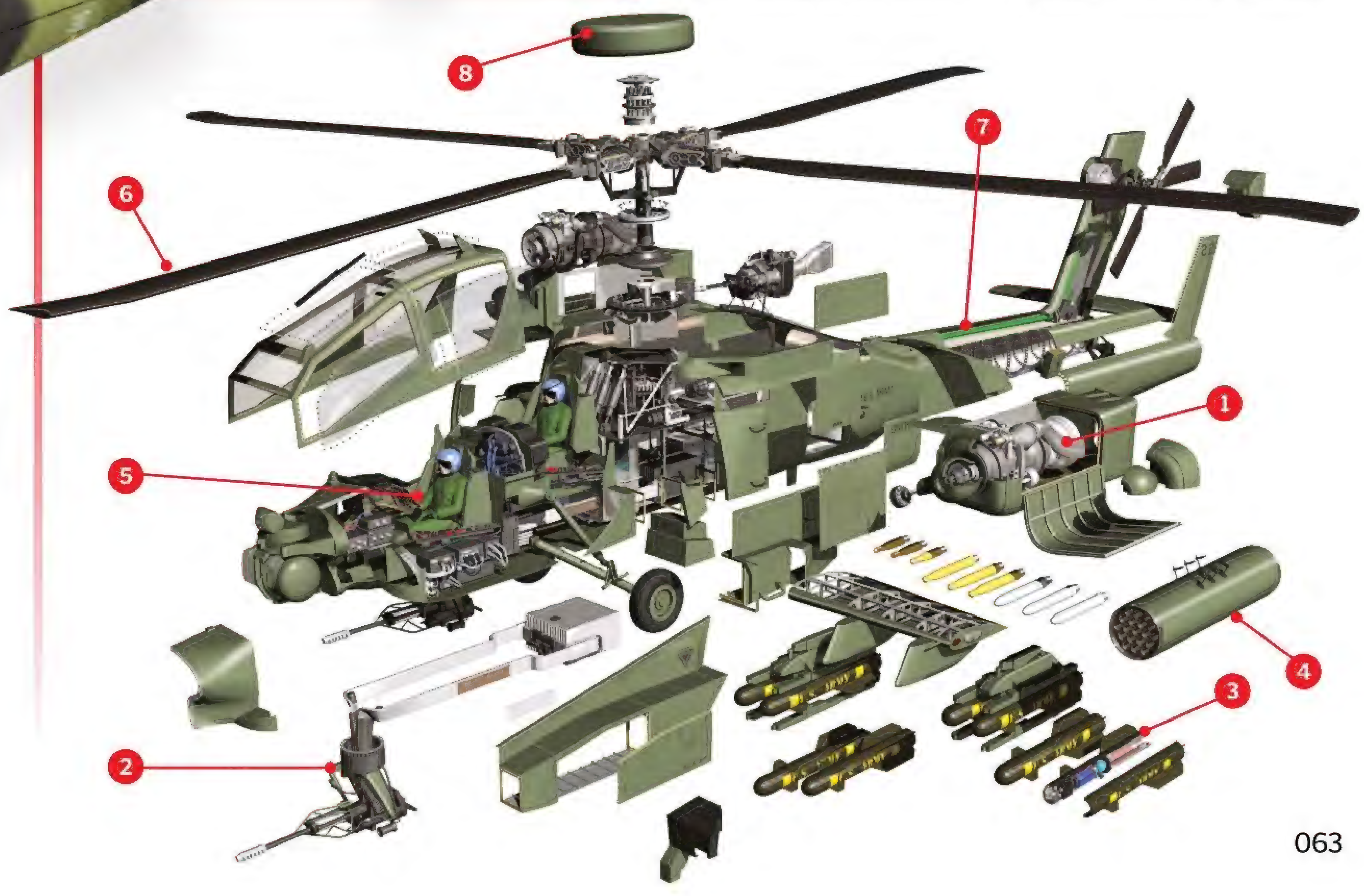
8. Radar dome
This system enables target detection from behind obstacles.

Power
The Tiger is powered by two 960kW turboshaft engines. The fuel tanks are self-sealing and explosion suppressive when exposed to enemy fire or in the event of a crash.

Fuselage
Kevlar, carbon laminates and Nomex make up 80 per cent of the airframe, and radar reflective surfaces are kept to a minimum.

Mistral missiles
With a 3kg warhead and a 6km range, the Tiger can cause significant air-to-air damage over long distances.

Weaponry
The Tiger can be fitted with different combinations of weapons depending on the variant, suitable for both air-to-ground and air-to-air combat.



The Bluecopter

Introducing Airbus' eco-efficient demonstrator – a game-changer that could make choppers more stealthy

The Bluecopter has allowed Airbus to test innovative, eco-friendly technologies

STEALTH HELICOPTERS

How tech can help make choppers a whole lot quieter

One of a military helicopter's biggest strengths is its manoeuvrability. Being able to take off and land in difficult terrain, move in any direction and hover makes gunships incredibly useful in battle. However, this advantage comes at a price and the sound of the rotor blades spinning almost negates any chance of a stealthy approach. Helicopter blades are noisy because of blade-vortex interaction (BVI). Each blade rotates at such a speed that high amounts of turbulence are caused. Huge amounts of air flow around the blades as they turn and a concentrated vortex (a whirling mass of air similar to a whirlwind) is formed. As each following blade cuts through this vortex, acoustic energy and vibrations are created, resulting in the classic chopper sound. It has been a long-standing issue but now various technologies are being implemented in an attempt to reduce it.

Airbus' Bluecopter has a new style of rotor blade that utilises Blue Edge technology. The innovative double-swept design reduces noise by four decibels by reducing the surface area of the blade that impacts on the vortex. This is complemented by Blue Pulse technology, which incorporates three flap modules into every blade. Directed by a flap rotor control that uses tiny electric motors powered by crystals, they move at up to 40 times a second, lessening the BVI as less pressure is created. This decreases the level of noise generated, as well as giving the pilot a smoother ride with a significant reduction in cabin vibrations.

Another method the Bluecopter is using to make it both greener and stealthier is a Fenestron. This encases the tail rotor and allows the mechanism to have more blades, which adds more thrust, while reducing drag and vibration. On the Bluecopter, stealth technology is used in conjunction with aerodynamic landing skid fairings and a T-tail stabilising rudder to increase efficiency and decrease emissions.

"The innovative double swept design reduces noise by up to four decibels"

DID YOU KNOW? Without protective headsets, UH-60 pilots would be exposed to over 100 decibels, enough to cause ear damage

Operation Neptune Spear

On 1 May 2011, US President Barack Obama declared to the world that Osama bin Laden had been killed. The operation that disposed of the founder of Al-Qaeda was codenamed Operation Neptune Spear and was undertaken in two Black Hawk helicopters supported by two MH-47 Chinooks. During the mission, one of the Black Hawks ran into difficulty and had to make a hard landing. It was reported that before leaving, the SEALs made efforts to destroy the downed chopper, leading aviation analysts to believe they were equipped with secret stealth technology. US authorities have remained tight-lipped on the matter, but photos of the surviving wreckage appeared to show modifications to the tail section to suppress noise and avoid radar.

The UH-60 Black Hawk has become the US Army's premier multi-role helicopter

TYPES OF MILITARY HELICOPTER MISSIONS

Powerful, agile and resilient, the Tiger is the chopper of choice in many situations

Ground fire support

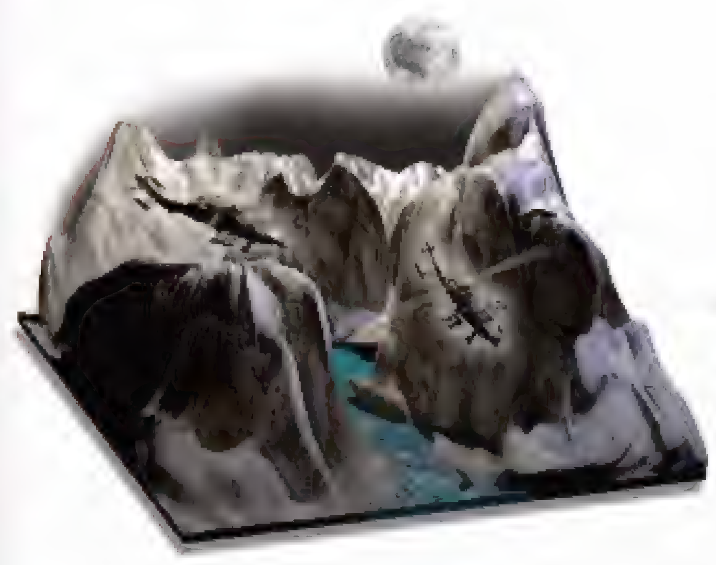
Infantry and armoured divisions on the ground can rely on the Tiger to provide backup. The 30mm gun is incredibly accurate and can fire at a maximum distance of 2,000m.

Amphibious operations

The Tiger HAD is also a worthy adversary at sea. It was designed to be able to land on aircraft and its low maintenance requirements mean it can stay out at sea for long periods.

Escort

Operations in Afghanistan, Libya and Mali allowed the Tiger to display its prowess as an escort chopper. It can easily eliminate threats and guide others to safety.



Armed reconnaissance

Day and night identification sensors make the Tiger a highly competent reconnaissance unit that can weave through tough terrain and also engage the enemy if it needs to.

Aerial combat

The twin attack power of a 30mm turreted gun and Mistral missiles are more than a match for any other helicopter. Also on board are 32 chaff and flare cartridges.

Anti-tank warfare

The range of powerful anti-tank missiles at the Tiger's disposal make it the ideal gunship. It can take out tanks from a safe distance, firing from up to 8,000m away.

Ask the expert

We spoke to Marius Bebesel, programme manager at Airbus to explain more about the Bluecopter

What sort of helicopter is the Blucopter?
Based on an H135, the Bluecopter technology demonstrator is a light, twin-engine helicopter. It is a flying technology test bed, on which Airbus Helicopters is able to trial next-generation eco-friendly technologies that can be applied across Airbus Helicopters' product line. The Blucopter is a unique, one-of-a-kind, test aircraft.

How environmentally friendly and energy efficient is it?
The Bluecopter allowed Airbus Helicopters to test performance and fuel management technologies (including an 'eco-mode', which shuts down one of the two engines during standard cruise) leading to a ten per cent reduction in fuel consumption, helping to achieve a 40 per cent CO_2 emissions reduction.

The demonstrator features several design measures to reduce the aerodynamic drag of the helicopter. This includes fairings for the main rotor hub and the landing skids, and a newly developed low drag aft-body concept.

The eco-friendly approach is extended even to the attractive paint scheme of the helicopter, which makes use of the latest water-based paint technologies.

Do you have plans for any electric helicopters?
Airbus Helicopters is researching lower emissions technology with its compound helicopter LifeRCraft and the High Compression Engine (using an advanced diesel engine instead of a turbine for light helicopters).

Airbus Group has teamed up with Siemens to research electric flight. It is thought that by 2030 passenger aircraft below 100 seats could be propelled by hybrid propulsion systems.

The innovative technologies used on the Raider allow it to reach much higher speeds than standard choppers

MILITARY HELICOPTERS: THE NEXT GENERATION

What does the future have in store for a new class of supercopter?

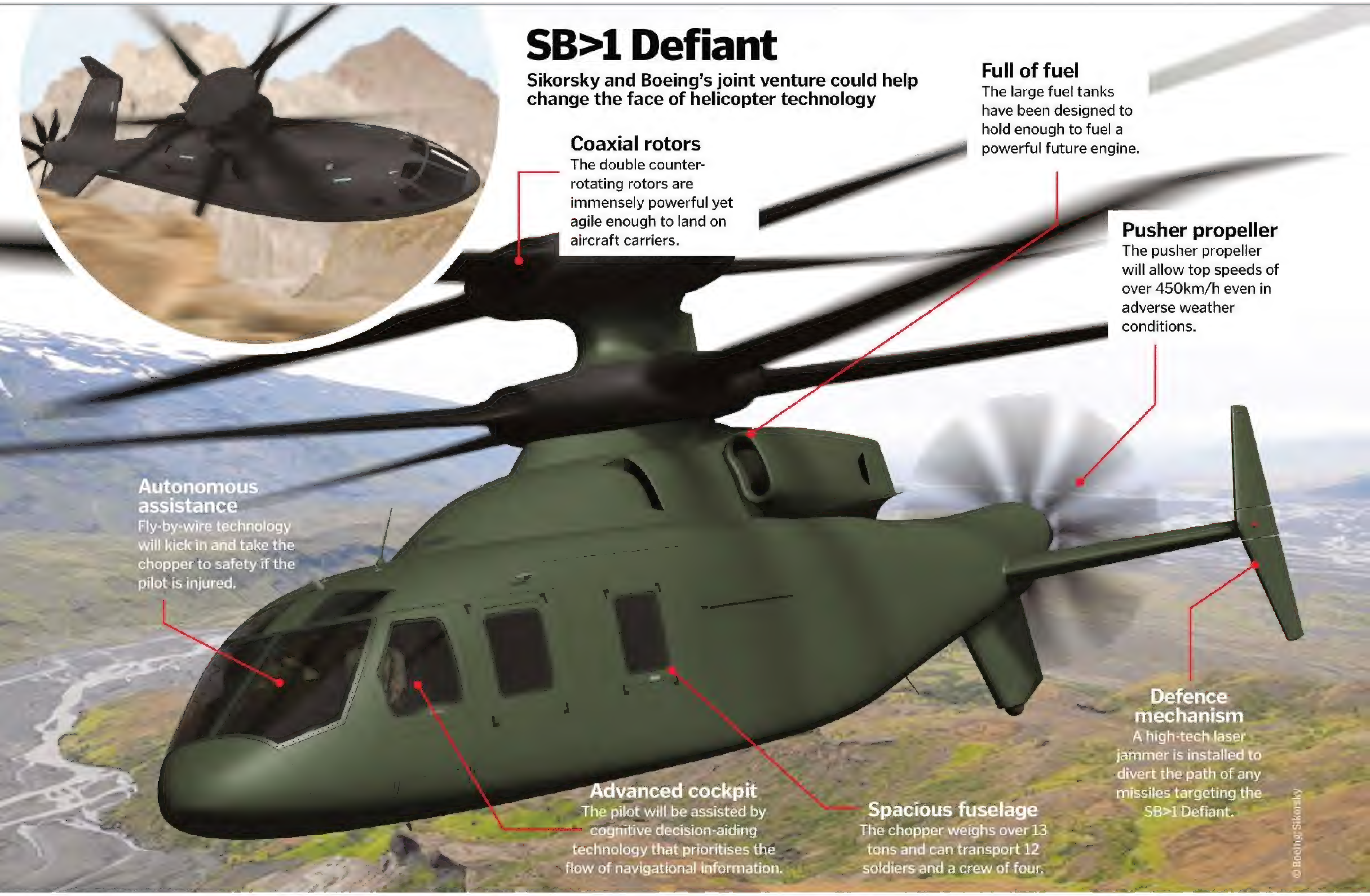
While the Boeing AH-64 Apache and the Sikorsky UH-60 Black Hawk are still capable gunships, even more advanced updates are on the horizon. Both companies are at the forefront of future helicopter design and are aiming to develop choppers that will boast twice the speed and twice the range of the current crop. The two aviation giants are currently joining forces to create the SB>1 Defiant while Bell and Lockheed has its own rival project in the shape of the V-280 Valor. Both ventures are demonstrator aircraft and will act as trial runs to potential future helicopter designs under the Future Vertical Lift (FVL) project. They will take to the skies for testing as part of the US Army's Joint Multi-Role programme in early 2017. FVL includes five all-new helicopters that will replace the current designs with a new breed of attack copter. As well as having first-class combat capabilities, the new helicopters will embrace semi-autonomous technology and be flexible enough to serve in urban security, disaster relief and medical evacuation. Each of the aircraft will use a new active system that will advise the crew on when components in the cockpit need to be replaced, while also giving as much assistance as possible to the pilot. Compatibility with other vehicles will be at the forefront of the new choppers' design. They will be capable of landing on ships and being stored on cargo planes. These ultra-advanced helicopters are set to be in production by 2030 and will serve the US Army, Navy, Air Force and Marine Corps.

"The new helicopters will embrace semi-autonomous technology"

As well as attack helicopters, the classic Chinook design will also be getting an overhaul.

SB>1 Defiant

Sikorsky and Boeing's joint venture could help change the face of helicopter technology



The Block II Chinook programme will see Boeing's iconic twin rotor vehicles undergo a modernisation project. They will still utilise the same basic design but will be kitted out with an assortment of modern technology. All the projects are a fascinating glimpse into the future and will build on the already cutting-edge technology used in today's helicopters. While drones continue their vital role on the front line of aerial combat, the attack helicopter will once again dominate the skies with more advanced engineering and weaponry than ever before.

The Raider's cockpit can fit two pilots and the cabin will have space for six soldiers

S-97 Raider

Sikorsky is currently developing a new generation of helicopter. Utilising innovative technology, the S-97 Raider has not one but two coaxial counter-rotating rotors. These rotors are mounted on the same shaft but rotate in opposite directions. This advanced rotor-wing technology will be accompanied by a push propeller at the rear and will enable the vehicle to reach altitudes of 3,000 metres even in the most challenging climates, travelling at twice the speed of the fastest helicopters currently in the air. As well as its superior performance, the Raider is designed to have a reduced turning radius and lower sound emissions than current helicopters. Its likely role within the military will be as a light tactical vehicle but it still packs a punch and comes equipped with Hellfire missiles. The Raider will be equally adept at armed reconnaissance and search and rescue missions and comes complete with retractable landing gear, vibration control and thermal management systems for this purpose.

The Raider conducted its maiden flight in 2015 and is currently still under development

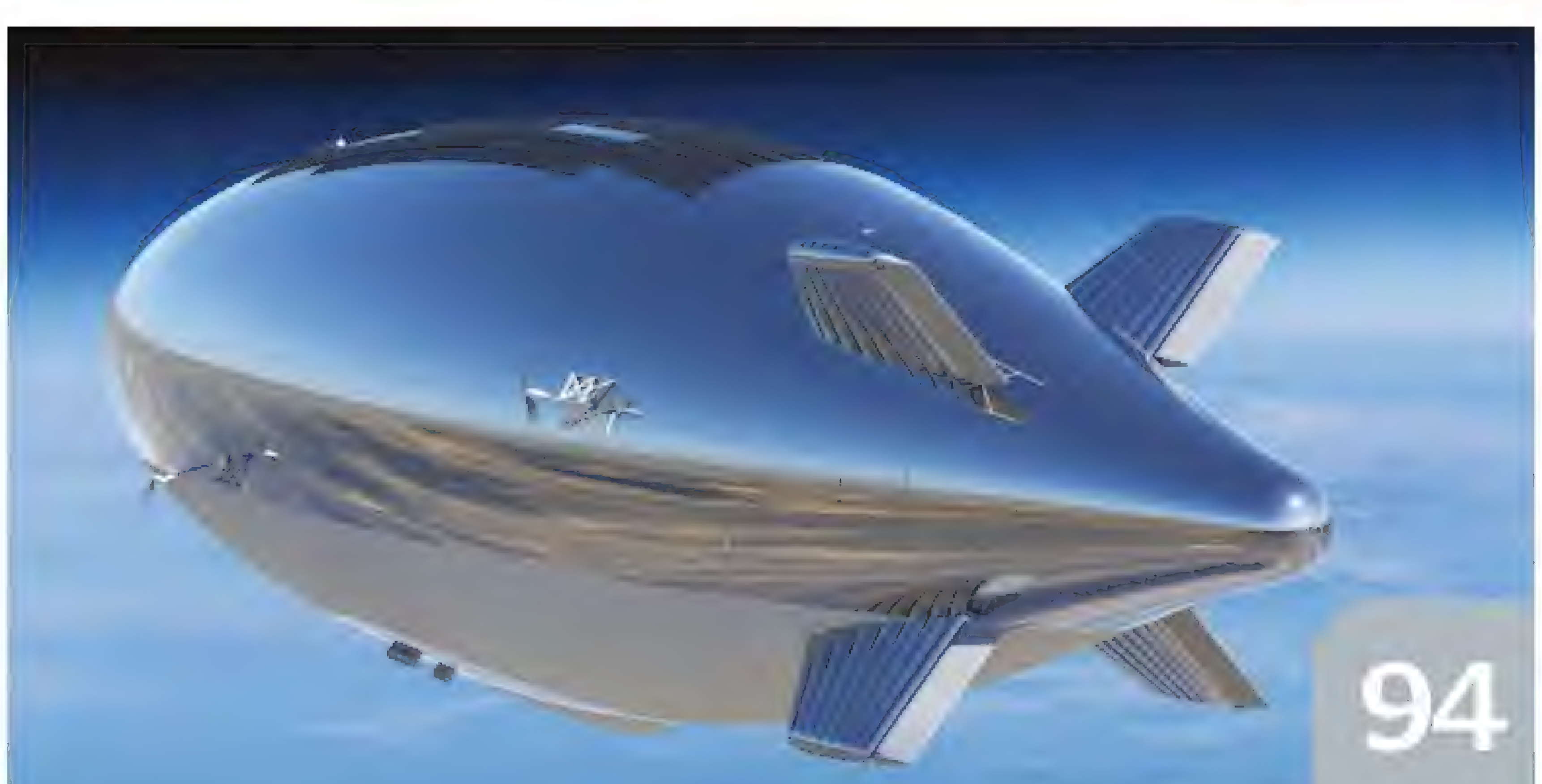
Commercial

76

84

82


98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70

DRONES

How unmanned flight will change your life

Also known as

1 The name drone refers to any aircraft without a pilot on board. They are also known as unmanned aerial vehicles (UAVs), remote piloted aircraft (RPA) or unpiloted air systems (UAS).

Future swarms

2 There are over 4,000 different UAVs in circulation on the global market and the FAA estimates that as many as 7,500 small commercial drones could be operational in US airspace by 2020.

Friendly drones

3 In Britain, manufacturers have suggested painting drones in bright colours as a way to make them appear friendlier and less reminiscent of warzones.

The first drone

4 The first powered UAV was the "Aerial Target" invented by Archibald Montgomery Low in 1917. It was launched using compressed air from the back of a lorry.

Control methods

5 Drones can be controlled in one of two ways; either autonomously by an on-board computer, or remotely by a pilot on the ground.

DID YOU KNOW? *The number of organisations allowed to use drones in the UK went up 80 per cent from start to end of 2014*

Drones are being used in air forces around the world, but the future is looking much more varied for the remote controlled aircraft. There is a fast-growing industry of autonomous flight that can both help and entertain the world, from rescuing people at sea to recording awe-inspiring aerial videos.

Disaster relief, for example, is a major area where drones can make an incredible difference. They can fly over the scene of an earthquake, nuclear meltdown or bomb site and capture high-resolution pictures or video to help the team on the ground organise a rescue or clean-up mission. Drones such as the Trimble UX5 could be of enormous benefit as the 2.4-gigahertz modems in the craft and the tablet can communicate over a distance of five kilometres (3.1 miles), enabling mapping to take place with the pilot nowhere near potentially dangerous rubble and aftershocks.

When the Fukushima nuclear power plant malfunctioned in March 2011, clean-ups and analysis of the radiation was limited due to the health risks posed to helicopter pilots.

Drones such as the Advanced Airborne Radiation Monitoring (AARM) system designed by Dr James MacFarlane at the University of Bristol could put an end to that. This particular craft is a hexacopter with a gamma spectrometer attached, which measures the amount of radiation being emitted from a chosen site. This can be done without a human anywhere near the area, so information can be received much more quickly and safely.


Drones offer a whole new perspective on video recording and photography

One of the most exciting commercial applications of drones is aerial photography and videoing. In the past, shooting any kind of media from the air required the hire of cranes or helicopters. Now, however, drone-mounted cameras can be bought for as little as £50 ($80), enabling amateur photographers and film-makers to capture amazing high-definition footage for a fraction of the cost.

Although drones might seem the futuristic domain of governments, the military and serious enthusiasts, there are a number of extremely practical day-to-day applications they can be used for. Amazon and DHL are both deep into the testing stage of delivery drones. You may remember the end of 2013 when Amazon claimed drones would be delivering small packages within five years. Currently the use of drones for commercial purposes is banned in the United States, but Amazon has petitioned the Federal Aviation Authority (FAA) to relax their rules to allow small drones to carry payloads of 2.3 kilograms (five pounds) to customers. This weight, they say, makes up 86 per cent of their deliveries and would take big, bulky and dangerous delivery vehicles off the road. DHL has already flown test missions from the German mainland to the island of Juist, off its northern coastline.

Commercial drones are a far cry from their headline-grabbing military cousins, but they are every bit as exciting, packed with fascinating technology and the ability to perform tasks that makes our lives, and the world, a little bit safer and a whole lot more fun.


The AARM won its inventor, Dr James MacFarlane, the 2014 ERA Foundation Entrepreneurs Award

LIFE-SAVERS

Discover the innovative drones designed to rescue those in need

The agility and efficiency of these incredible machines often means they are better equipped than humans or other vehicles for humanitarian tasks . From transporting aid to spotting someone in need, there is a variety of potentially life-saving drone aircraft projects that are currently in development.

One such initiative is the LifeLine Response app, a personal panic button that will summon a drone if you are in distress. If you are concerned about your safety, you can simply load the app and keep your thumb pressed on the screen or set a timer. If you get into trouble, you can release your thumb or fail to deactivate the timer, and the police will be called and a drone deployed to your location using GPS.

The idea is that the drone, which can travel at 97 kilometres (60 miles) per hour, will be able to scare off an attacker by sounding an alarm, follow them if they flee the scene, and collect information from the area before the police arrive. It is hoped the system could be used in cities across the world, with dozens of drones stationed at each law-enforcement headquarters waiting to spring into action.

Another concept, developed by Dutch engineering student Alec Momont, involves 'ambulance drones' quickly delivering defibrillators to heart-attack victims. The drone would be able to transport the equipment within minutes, and then the operator can use two-way video supported communication to instruct a nearby helper to use it.

While some life-saving drones are still a work in progress, others are already being put to work. For example, Draganflyer drones are being used to provide a unique high-resolution view of disaster zones and crash sites to help teams on the ground locate victims, organise rescue missions and document the scene.

Draganflyer makes several different models of drone suited to both hobbyist and professional applications. These come with a choice of camera, including a GoPro and thermal-imaging camera, and are flown using a handheld controller, but you will need some training in order to operate one.

Draganflyer X6

The main components of a life-saving drone

Draganflyer story

We spoke to Kevin Lauscher from Draganflyer about the incredible innovations of the X6

What is the main purpose of the X6?
The Draganflyer X6 was developed as a safe and easy-to-use platform to carry an aerial imaging system that provided clear high-resolution images. At the time of development, systems that could carry a high-resolution camera were generally large, dangerous and difficult to control.

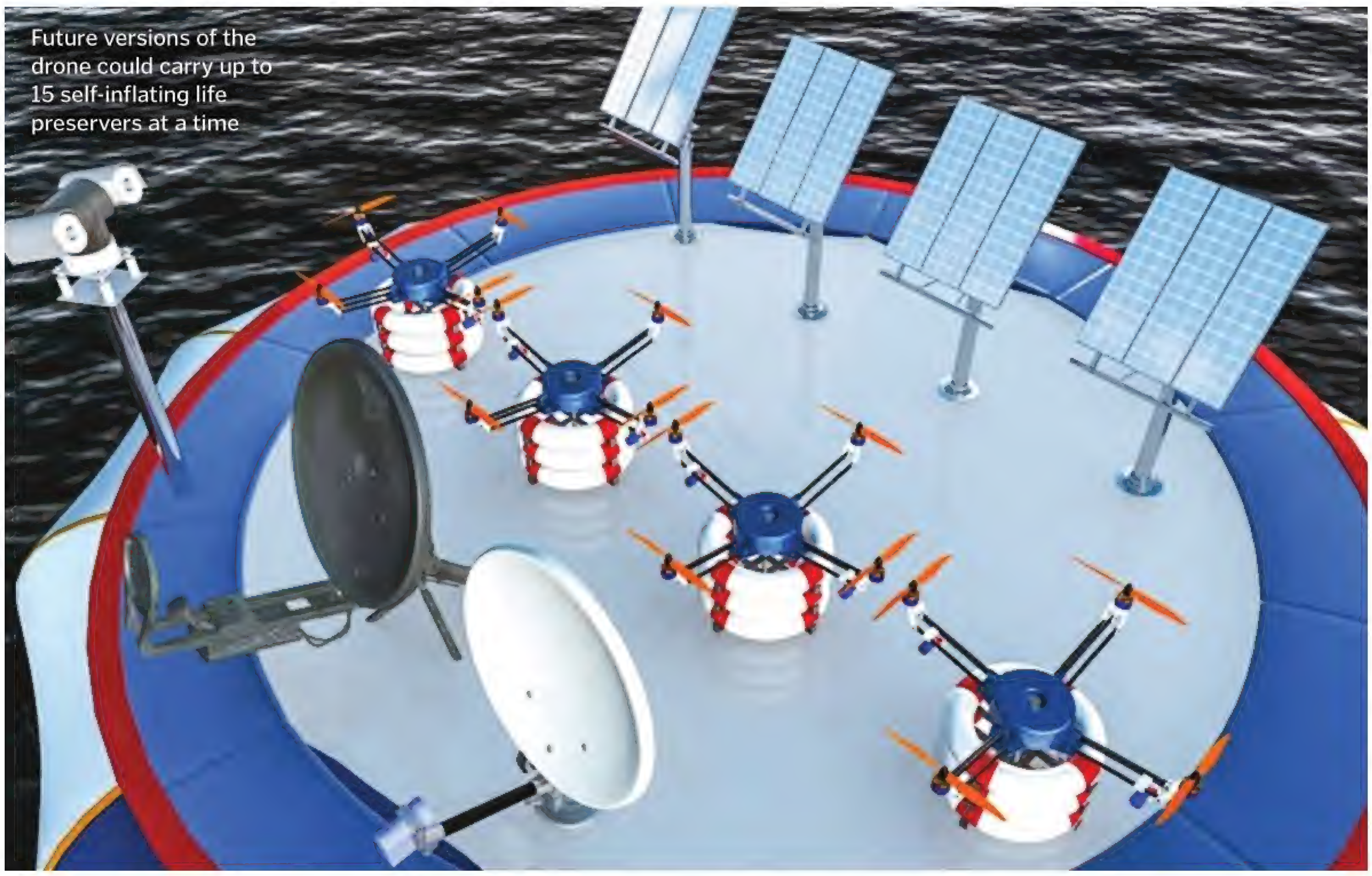
What sets it apart from other drones in existence?
It has a unique design with six rotors in the Y-style configuration, as well as its ability to fly even if it is missing one of the rotors. When it was first released, the concept of using sUAS (Small Unmanned Aircraft Systems) for civilian purposes was practically unheard of, so the attention it received made it stand out from other models.

What are your hopes for the X6 in the future?
The Draganflyer X6 was our first industrial system and was responsible for setting a lot of firsts for the industry. Since then we have developed other improved systems based on our experience with the X6. Our hopes are to work some technology upgrades into its design and for it to again become a front-runner in the sUAS world.

The Draganflyer X6 can carry cameras weighing 335g (11.8oz) or less, including a GoPro

LIFEGUARD DRONE

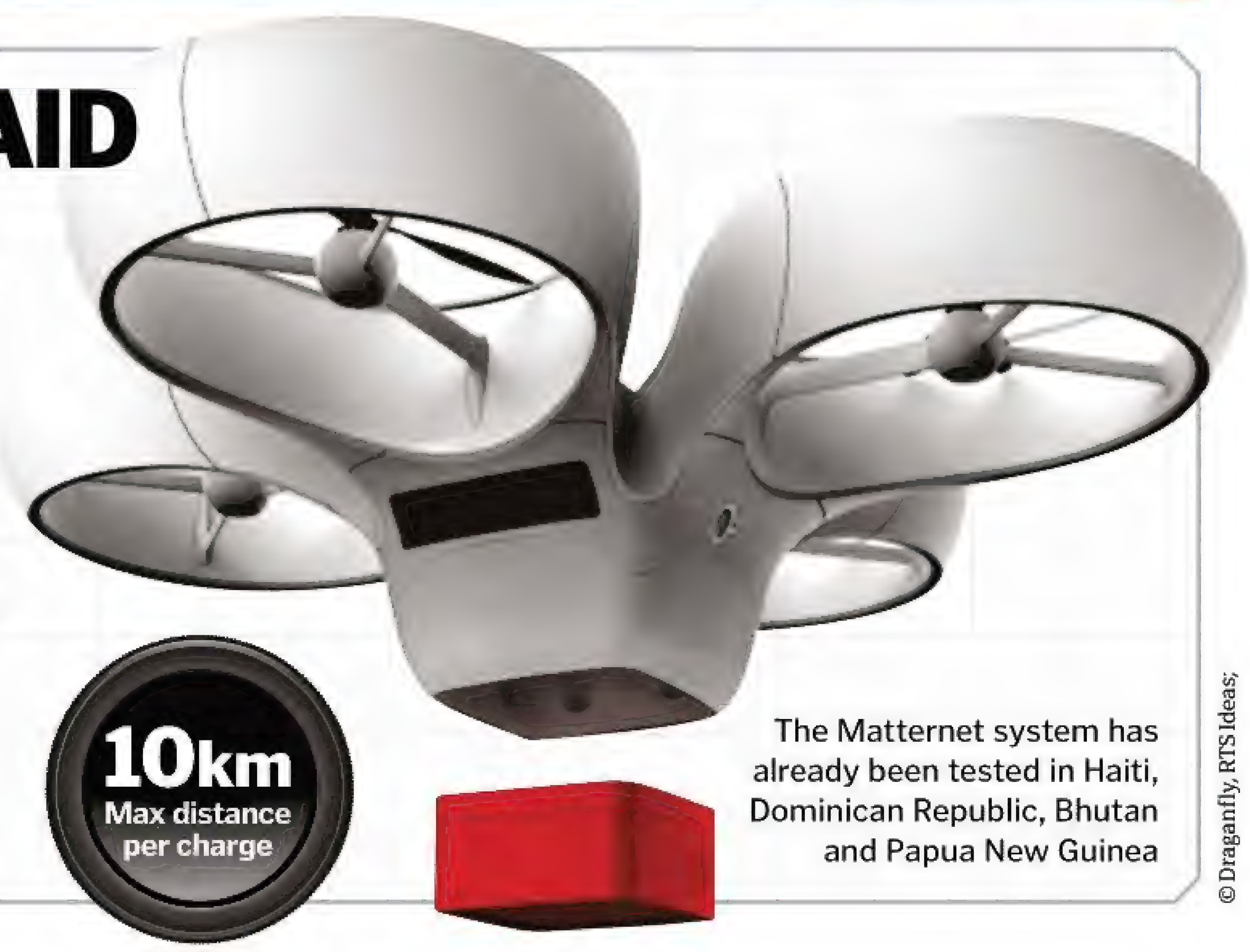
Getting help to those in trouble out at sea is especially difficult and slow, particularly in adverse weather conditions. Iranian company RTS Lab hopes drones can solve this, as it is currently developing a new lifeguard robot called Pars. After hearing about the huge number of people that drown in the Caspian Sea each year, RTS Lab decided to create a multirotor drone that could help save human lives. As well as being able to fly above the water and be guided by GPS, Pars can also carry and drop life preservers to where they are needed. Although it is not able to pull people to safety, it can provide initial aid before the lifeguard arrives and monitor the situation by recording photos and video. A prototype has already been tested, and was able to reach a target 75 metres (246 feet) out to sea in just 22 seconds, while a human lifeguard took over a minute.



Future versions of the drone could carry up to 15 self-inflating life preservers at a time

DELIVERING AID

In many developing countries, rural roads become inaccessible during the rainy season, making it very difficult to transport much-needed medicine to those in need. Matternet – a network for transporting matter – aims to provide the solution. The plan involves autonomous drones, carrying up to two kilograms (4.4 pounds) of medical supplies, flying between several ground stations. These stations would allow the drones to collect or drop off their payload as well as swap batteries so they can keep flying for longer. The drones will use GPS and other sensors to navigate and an operating system would make sure they avoid adverse weather conditions and do not collide with each other.



The Matternet system has already been tested in Haiti, Dominican Republic, Bhutan and Papua New Guinea

The Parrot AR.Drone 2.0 is controlled via an app on your Android or Apple device

COMMERCIAL USE

The drones offering film-makers a whole new perspective

Drones such as the Parrot AR and the DJI Phantom 2 Vision+ have added a thrilling new dimension to personal photography and filmmaking. These clever gadgets are becoming more and more affordable for amateurs looking to capture Hollywood-style footage from unique angles. A Parrot AR. Drone, for example, will only set you back around £320 ($300) and has a built-in camera that can shoot 720-pixel high-definition video. It generates its own Wi-Fi hotspot so you can control it from up to 50 metres (165 feet) away via an app on your smartphone or tablet. The app also shows a live stream of the video being captured and lets you change its direction by simple tilting your device. It can even perform impressive flips in mid-air, and you can program automatic movements to compose your film like a professional director. If you do happen to crash the drone while filming a daring action sequence, then you can have a go at repairing it yourself as all of the parts and instructions are available online. Due to the relatively recent advancement of commercial drone technology, many countries are still developing laws regarding their use in public spaces. In the United States, the Federal Aviation Administration currently limits drones to be flown below 122 metres (400 feet), away from airports and air traffic, and within sight of the operator.

Using drones in a professional capacity requires a certificate of approval from the FAA, but it has recently granted six movie and television production companies permission to use drones on their sets. Some big blockbusters, such as *Skyfall* and the *Harry Potter* movies, have already been shot using unmanned drones for aerial footage, but filming took place in countries where this was allowed.

We are already seeing more and more drone-shot sequences on the big screen. Not only is this great news for us cinemagoers, as we will be treated to more creative camera angles, but it will also save the production companies a lot of money on helicopter and crane bills as they try to get above the action while filming.

RECORD BREAKERS
DRONING ON

14 DAYS

LONGEST DRONE FLIGHT

The solar-powered Zephyr drone developed by UK firm QinetiQ flew for 14 days and 22 minutes in 2010, breaking the world record for the longest drone flight.

DID YOU KNOW? TV coverage of skiers and snowboarders at the 2014 Winter Olympics in Sochi was shot by unmanned drones

Hull
The hull is attached to the body by a pair of magnets. This protects the electronics.

Central cross
Made from rigid yet lightweight carbon fibre, the central cross contains wires that control and provide power to the four motors.

Camera
The HD camera shoots 30fps at 720p, streaming it directly to your mobile phone.

Ultrasound altimeter
The ultrasound altimeter judges how high it is by the time it takes ultrasound waves to return from the ground.

Gyroscope
The Invensense IDG 500 gyroscope is an advanced sensor that separates the X and Y-axes to quickly determine its position.

BEST FOR... VIDEO STREAMING

DJI Phantom 2 Vision+
Price: £500/$625 • **Get it from:** www.dji.com

BEST FOR... EVERYDAY FUN

Parrot MiniDrone Rolling Spider
Price: £90/$100 • **Get it from:** amazon.co.uk

BEST FOR... BEGINNERS

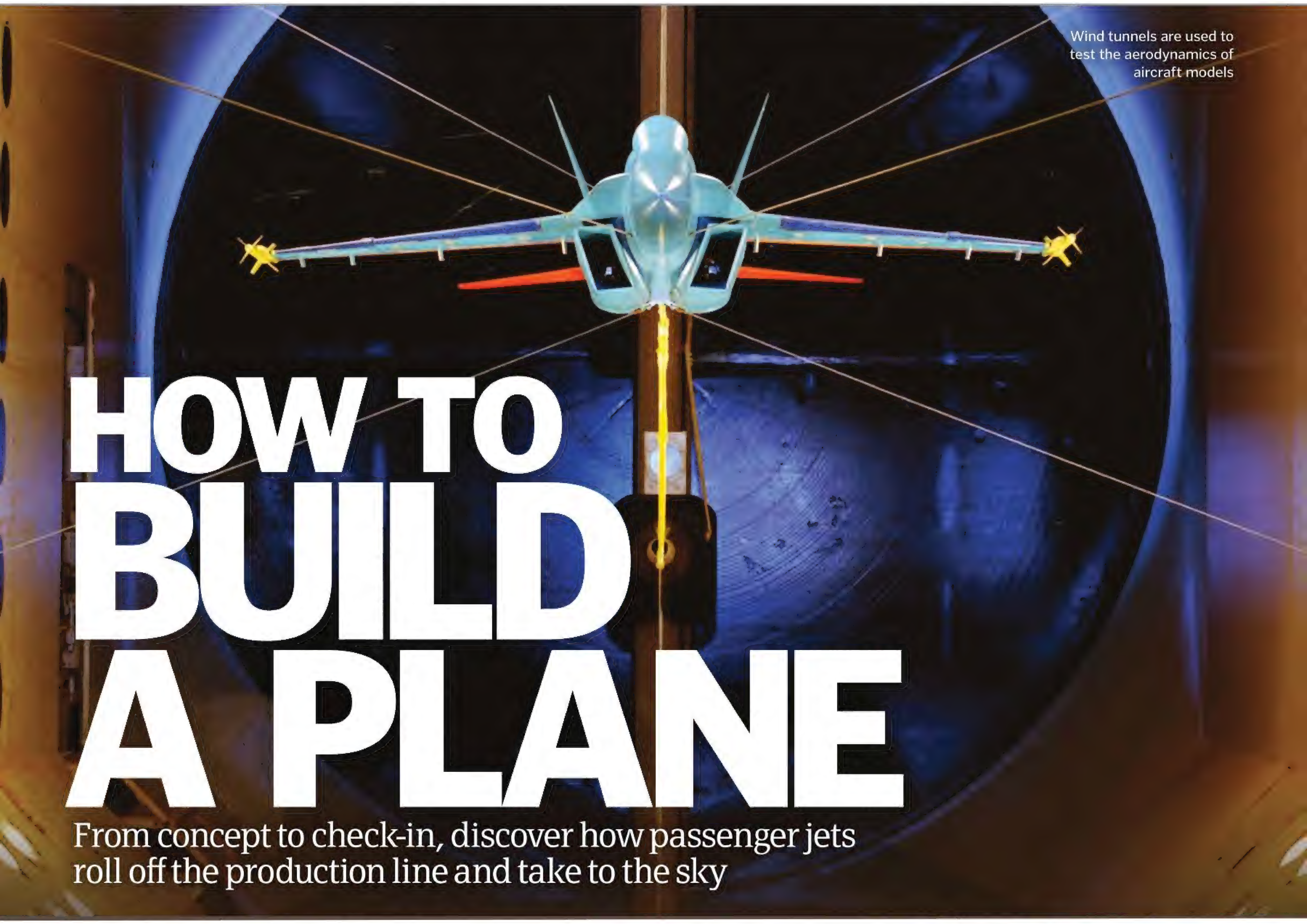
Walkera QR Ladybird V2
Price: £50/$79 • **Get it from:** walkera.com

BEST FOR... STUNTS

Blade 350 QX V2
Price: £340/$575 • **Get it from:** quadcopters.co.uk

BEST FOR... AFFORDABILITY

Hubsan X4 H107
Price: £45/$70 • **Get it from:** amazon.co.uk



Wind tunnels are used to test the aerodynamics of aircraft models

HOW TO BUILD A PLANE

From concept to check-in, discover how passenger jets roll off the production line and take to the sky

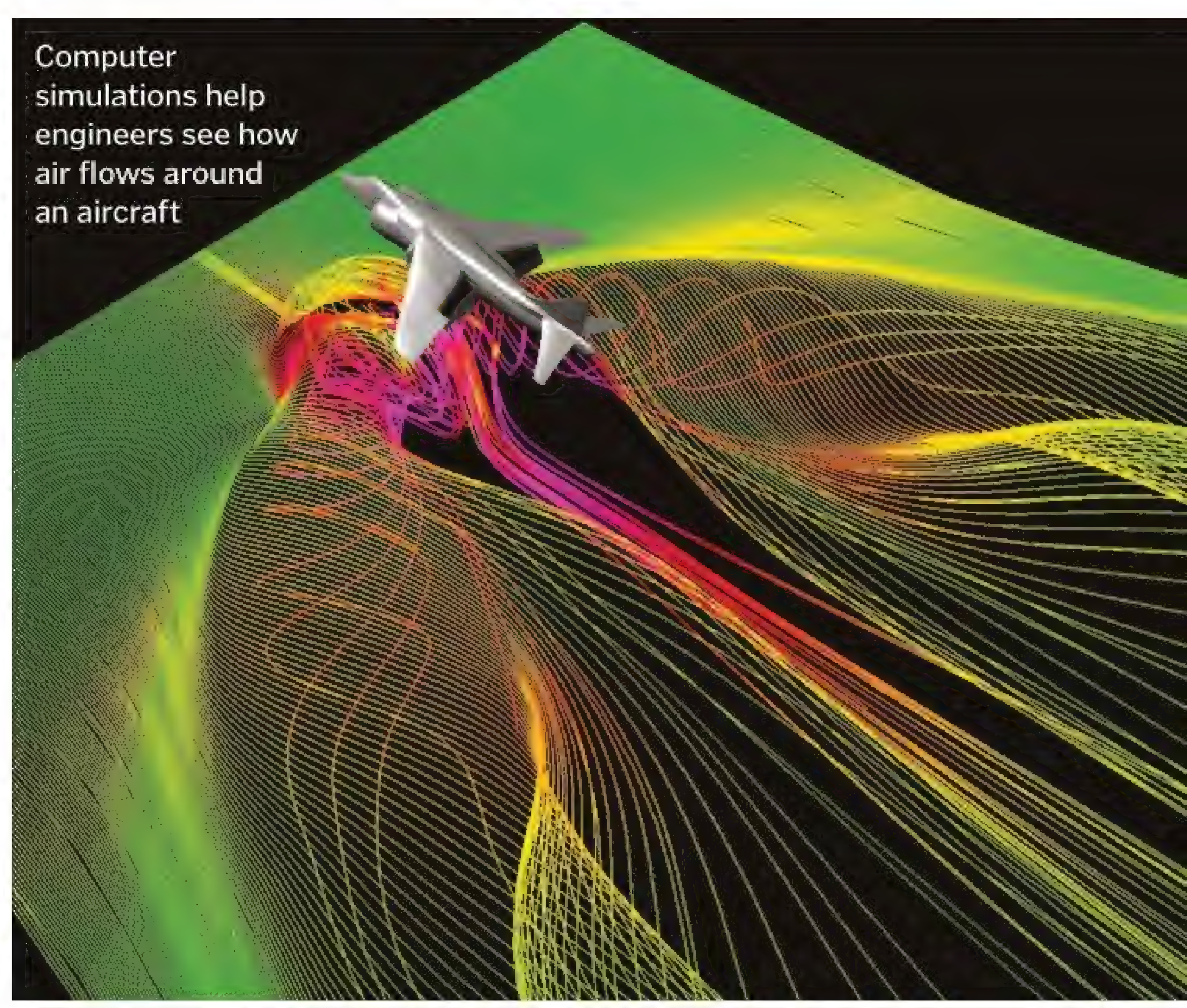
STEP 1: Design and testing

Before building can begin, the aircraft must first be designed in great detail. Thousands of engineers across the world often work together to design one plane, and it can take several years to get it right.

When designing an aircraft, there are four main areas to consider. First it must be aerodynamic, so that air flows around it with as little resistance as possible. To test this, engineers create computer simulations of the plane and examine how airflow and pressure will affect the body and wings when it is in flight. They then build a scale model of the aircraft and place it in a wind tunnel, where air is blown towards it at varying speeds in order to test its flight performance.

Next they must design the engines, making sure they are powerful enough to keep the aircraft in the air, fuel efficient to minimise running costs and pollution, and not too noisy. The way the plane handles in the air must also be considered, and so flight simulators are used to ensure it is easy and safe for the pilot to fly.

Finally, engineers determine what material to build the aircraft from, considering strength, weight, durability and cost, and how exactly it will be built.



Computer simulations help engineers see how air flows around an aircraft

STEP 2: Making the parts

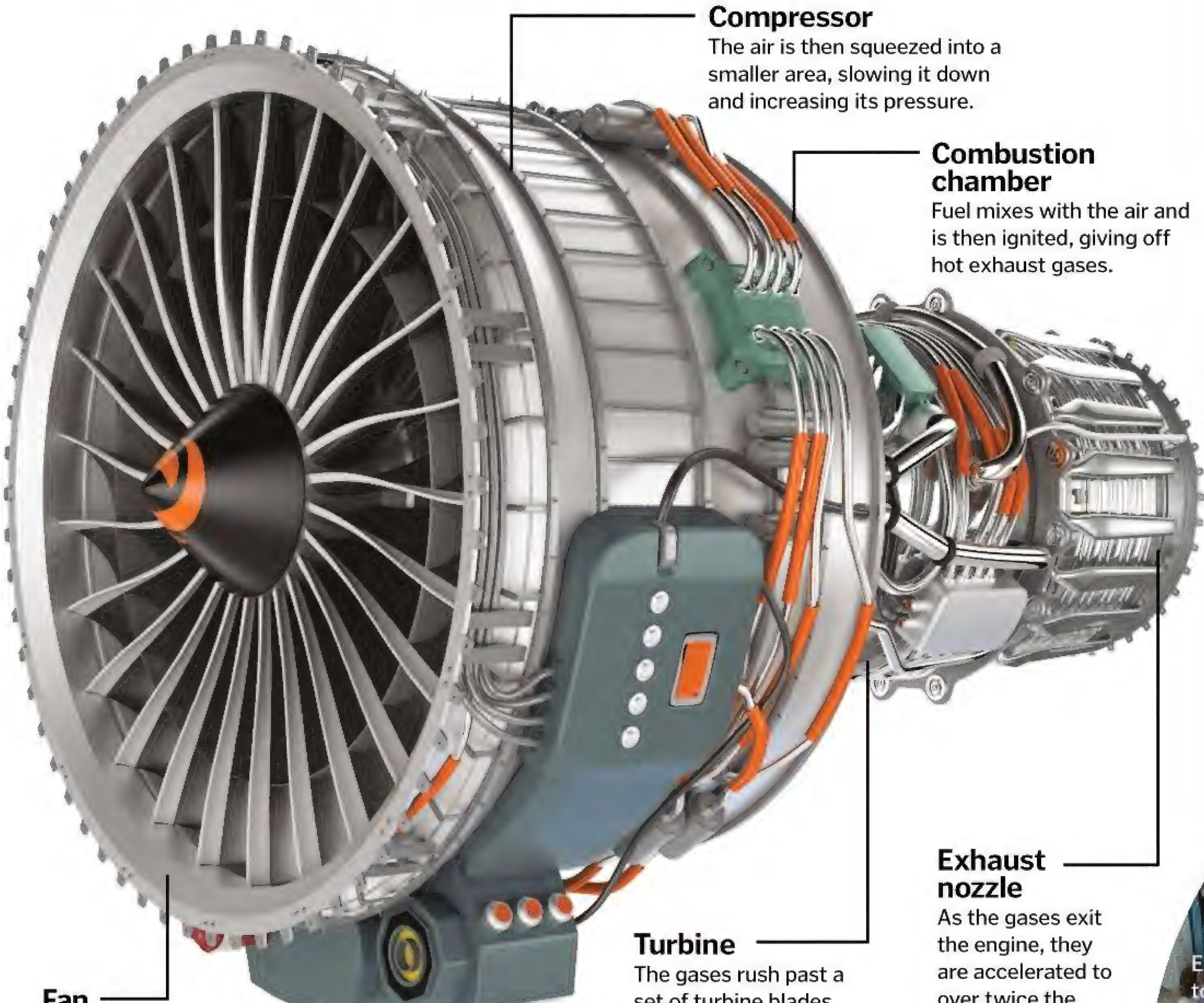
A plane is made up of millions of different parts, from the enormous fuselage shell to the tiny rivets that hold it together. Many are made by the aircraft manufacturer itself, while others, including the engines and landing gear, are produced by external contractors. A huge number of different skills are required to build an aircraft, from mechanics and electronics, to plumbing and painting, so it takes teams from all over the world to make the finished product. Coordinating the production of a plane is a task in itself, as everything has to be made to a tight schedule and then transported to where it is needed for assembly. Plus, each part has to undergo rigorous testing to ensure it functions properly and is safe to use in the final aircraft.

Engineers building the aircraft spars, supporting beams that run the length of the wings

2.65 million
The number of parts in an Airbus A350 jet

How do jet engines work?

The machines that turn fuel into thrust



What is a plane made of?

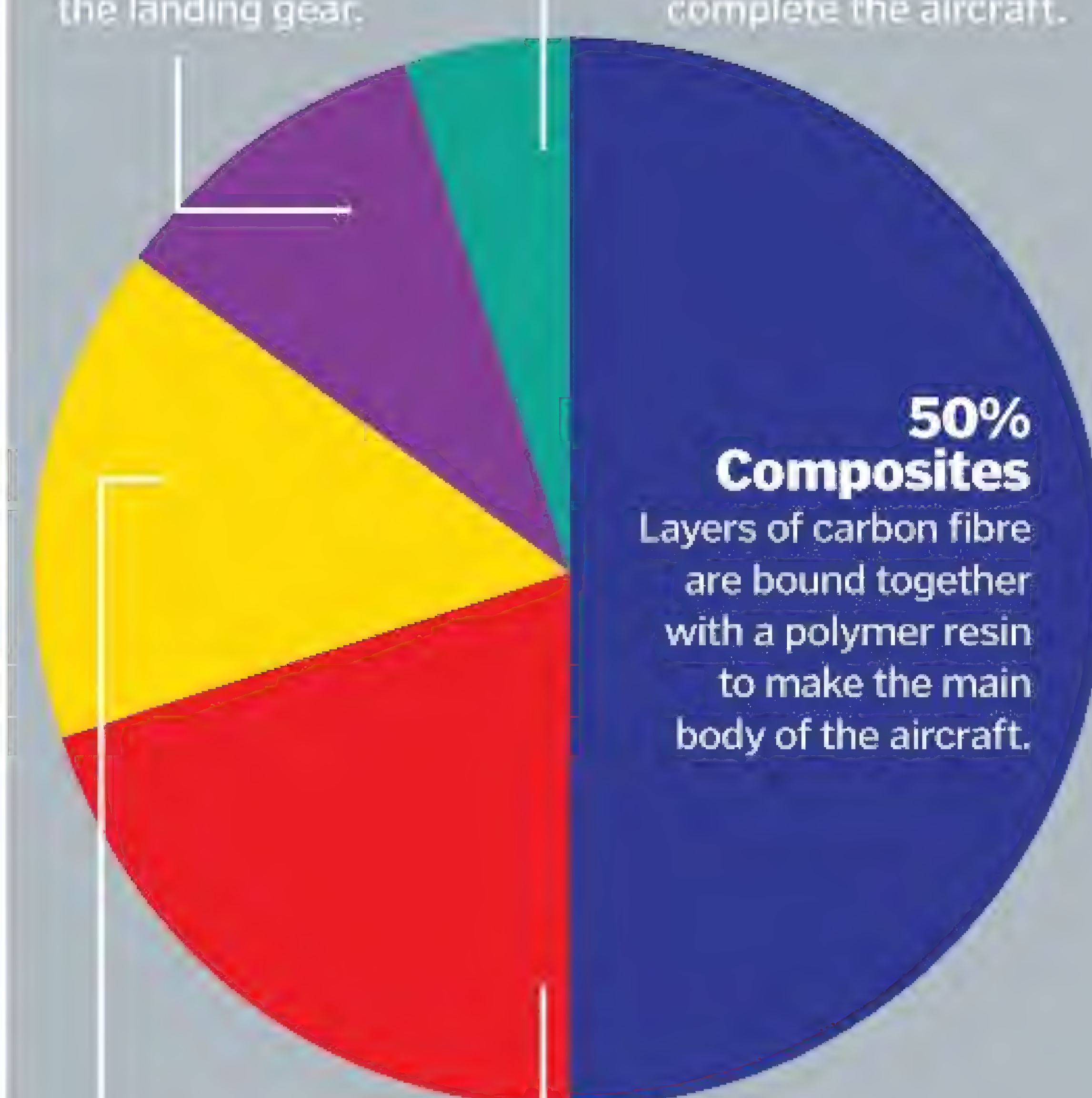
The very first planes were built from wood and fabric, but thankfully modern aircraft are made of much stronger – and less flammable – stuff. Metal was once the material of choice, with strong, light aluminium used to build the main airframe and outer skin, but it was soon discovered to be corrosive and susceptible to stress.

Nowadays, manufacturers favour composite materials, which are stronger and more durable, yet still incredibly lightweight. To build the wings and fuselage of an aircraft, layers of carbon fibre and resin are built up, like layering several strips of sticky tape on top of each other.

The entire aircraft part is then placed in an enormous oven, called an autoclave, to harden the composite material until it becomes incredibly strong. Once it is complete, the windows and doors are cut out, and the whole thing is covered in a green protective coating, ready to be assembled.

What's in a plane?

The materials used to build a typical jumbo jet



Enormous ovens are used to harden the composite material on an aircraft

STEP 3:
The final assembly

Putting together an enormous passenger jet requires an even more enormous building to do it in. Aircraft hangars are some of the largest buildings in the world, and are able to house several aircraft at once as they are passed from team to team along the assembly line.

First though, all the parts need to get there, and this is done by road, river and even air. Cargo aircraft such as the Airbus Beluga and Boeing Dreamlifter, are designed specifically to transport large pieces of aircraft to the final assembly point.

The individual pieces of the fuselage are fastened together using thousands of rivets, then the electrical and hydraulic systems, plumbing and insulation are installed. Next the wings are connected, using laser alignment to ensure they are perfectly level, and the landing gear is fitted underneath. This is followed by the tail, vertical stabilisers and an auxiliary power unit, which provides power to the aircraft when the engines are turned off. The cabin and cockpit interiors are then added, complete with seats and toilets.

Last of all, the engines are installed, as these are the most expensive component of the aircraft, representing over a third of its total value. Once assembly is complete, the plane is painted – this can take up to a week, depending on its size.


Planes are assembled in huge aircraft hangars by thousands of engineers


Aircraft slowly move along the assembly line as new parts are added


Giant cranes lift the parts of the fuselage in place, ready to be connected

72,000 square metres
The size of the Airbus aircraft hangar in Toulouse, France


The engines are fitted last, as they are the most expensive part of the aircraft

The Airbus Beluga cargo plane is so-called because it resembles a beluga whale

STEP 4: In-flight testing

If the aircraft is a new design, then the first few planes to roll off the assembly line undergo extensive prototype testing. This involves fitting them with a variety of sensors, and flying in extreme conditions, such as very hot and cold climates and really high altitudes. The individual elements of the aircraft are also tested, as the wings are forcibly bent to evaluate their strength, and dead birds are fired into the engines to see how they would cope with a bird strike.

To ensure the plane can withstand the stress of multiple take-offs and landings, computer-operated hydraulic jacks place heavy loads on the airframe for extended periods of time, and the plane may even be subjected to artificial lightning strikes to see how it performs in a storm. Once the first few planes have been rigorously tested, all successive aircraft are taken on their own test flights before they are deemed airworthy and delivered to airlines around the world.

Aircraft are tested on their ability to land on a waterlogged runway

Aircraft wings must be able to bend by nearly 90 degrees without being damaged

Ready for take-off!

"It can seat up to 19 people in upper class comfort"

The luxury of the Lineage 1000 jet

A luxurious hotel in the sky? It's yours for a few million dollars

The best private jets offer more than just rows of seating and the Lineage 1000 includes a shower room, a double bed, a lounge and an office, a bar and almost everything else you need in a space that is three times larger than traditional business jets. It can seat up to 19 people in upper class comfort and the interior has been built to include five privacy areas, Wi-Fi and real-time flight displays, all thanks to the larger space and innovative interior design. On top of this the turbofan engine technology and fuselage interior design ensure low noise for passengers.

Safety has not been ignored and the pilot has a CMC (central maintenance computer) at hand to predict potential problems and offer solutions, plus an enhanced vision system to improve awareness at all times. Many of the systems are integrated into the jet itself, rather than added on, which reduces weight and other design enhancements increase approach steepness which is ideal for landing in smaller airports.

One of these enhancements is Smart Probe, which will sense airspeed, trim and altitude to ensure the most accurate positioning at all times. To sum up, the Lineage 1000 offers the ultimate flying experience thanks to the designers pushing the envelope in every single area of the design process.

Filthy-rich airlines, you are clear for take off

4. Catch up
Multiple large displays offer entertainment, internet and other facilities which will keep you busy no matter how long the flight is.

5. Need a restaurant?
The dining area is the perfect way to enjoy your in-flight meal, which is highly unlikely to be served on plastic trays.

6. Preparing food
The galley area is where food and drinks will be prepared. It can be sealed off from the rest of the cabin so as not to ruin the ambiance.

8. The serious stuff
Inside the cockpit are some seriously clever systems designed to aid safety and ensure the least disruption possible.


What the opposite to economy class looks like!

HEAD 2 HEAD
LUXURIOUS PRIVATE JETS

LUXURIOUS

1. Falcon 7X
The Falcon 7X offers a mere 39-foot long cabin,but the advanced environmental systems still make for a very pleasant journey.

MORE LUXURIOUS

2. Gulfstream G650
The Gulfstream is designed to offer flexible comfort and succeeds, and at 53 feet offers great scope for individual cabin design.

MOST LUXURIOUS

3. Embraer Lineage 1000
With a cabin length of 84 feet the Lineage 1000 is easily the most luxurious thanks to the comfort and individualism offered in every corner.

DID YOU KNOW? *The Lineage 1000 interior can be configured from 25 different cabin modules*

Pure airborne luxury

1. Stay awake
The 84 foot long cabin offers a huge amount of space, which can be configured into various private areas for maximum comfort.

7. More than a wardrobe
The 351 cubic feet walk-in baggage compartment lets you take your entire wardrobe with you and there's still room for your other luxuries.

3. Freshen up
A fully equipped luxurious bathroom will help you arrive at your destination fresh as a daisy and the fittings rival the best hotels.

No better place to join the mile high club

2. Get some sleep
A double bed will ensure you catch up on the sleep you need or you can just lie back and enjoy the large display on the wall.

9. The power
The turbofan engines ensure the quietest and smoothest possible flight and also offer a longer range than many other private jets.

Know your engines

© Gulfstream Aerospace Corp

Jet engines are almost universally used to power private jets and passenger aircraft, but there are some significant differences between the type used on each. Private jets often use high-bypass turbofans, which are very quiet and offer enhanced fuel efficiency plus excellent thrust to ensure better performance. These engines are usually placed below the wing to reduce drag and turbulence, particularly during take off, which is crucial for a small passenger plane. Tests have proved that turbofan engines are highly reliable and that most pilots should never suffer an engine incident in their entire career. The Gulfstream G550 is one example which is powered by twin Rolls-Royce turbofans.

The statistics...

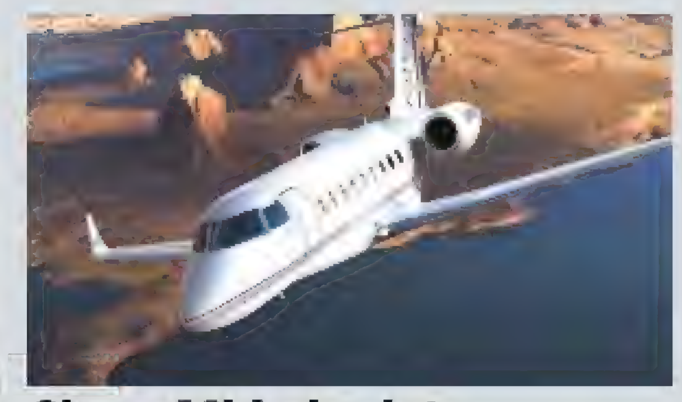
Lineage 1000

Manufacturer: Embraer
Class: Heavy jet
First flight: 26 October 2007
Wingspan: 28.72m
Length: 36.24m
Height (outside): 10.28m
Cabin height: 2m
Cabin volume: 115.7m^3
Cabin area: 68.85m
Weight max payload: 55,000kg
Max speed/cruise speed: 480 knots/469 knots
Propulsion: GE CF34-10E turbofans (x2)
Ceiling: 12,497km

Know your jets

Class: VLJ
Passengers: 4-8
The VLJ (very light jet) is often used as an air taxi to travel between local airports in a country.

Class: Light jets
Passengers: 5-9
Light jets are similar to VLJs in their target market, but are faster and offer some extra luxuries for quick journeys.



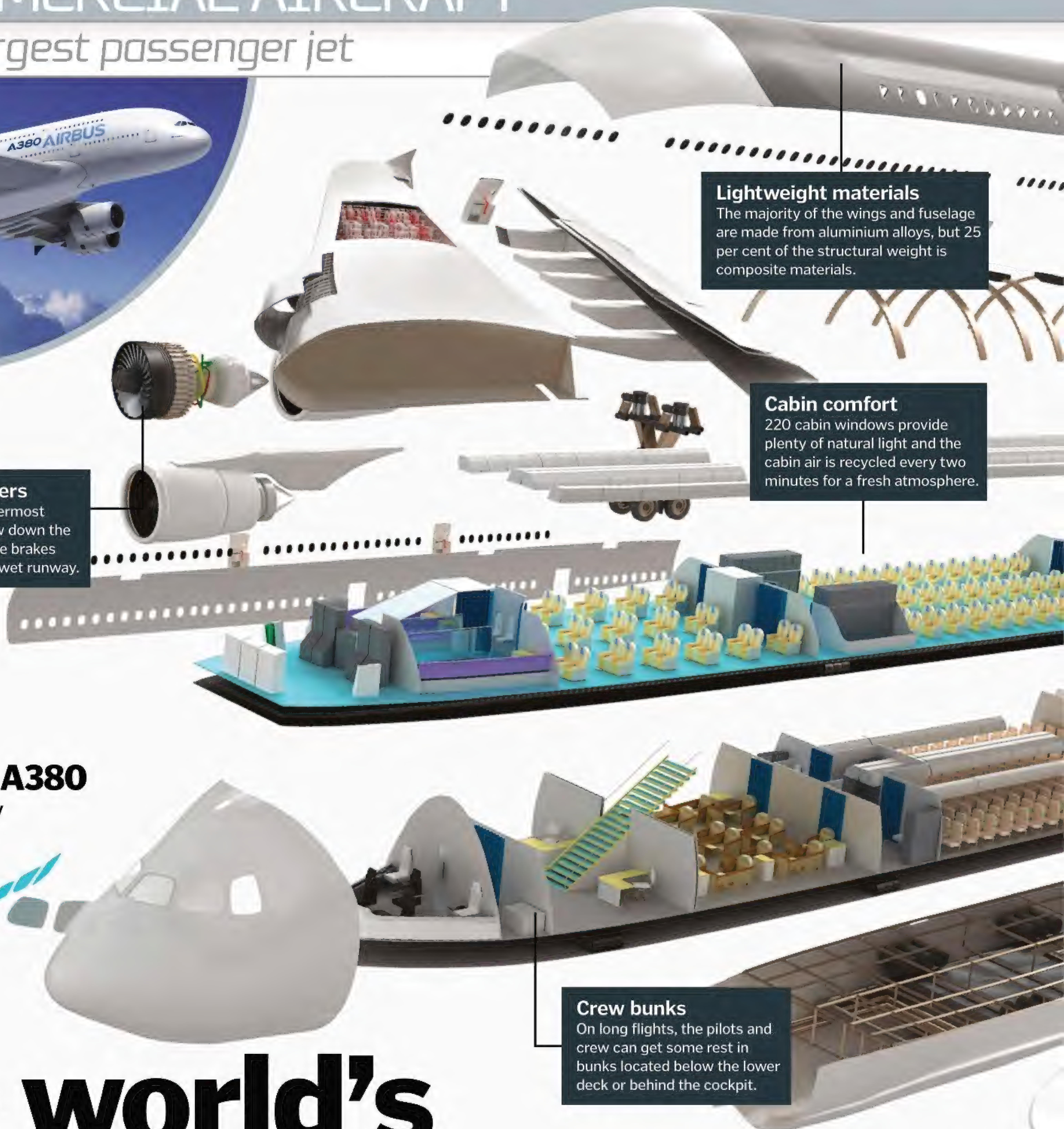
Class: Mid-size jets
Passengers: Up to 18
Mid-size jets typically carry 8-12 people, but some can accommodate 18 people for short flights.

Class: Super mid-size jets
Passengers: Up to 19
These jets are designed to offer luxury for transatlantic flights and give more cabin space and luxuries.

Class: Large size jets
Passengers: Up to 19
Large size jets are designed for longer distances and New York to Tokyo is quite possible with high levels of comfort.

Class: Heavy jets
Passengers: 100s
Heavy jets range in size and can be privately hired. The Lineage 1000 is in this class, but is small compared to some.

The Airbus A380 is greener and quieter than many other passenger jets



Boarding the A380

The incredible technology inside this sky giant

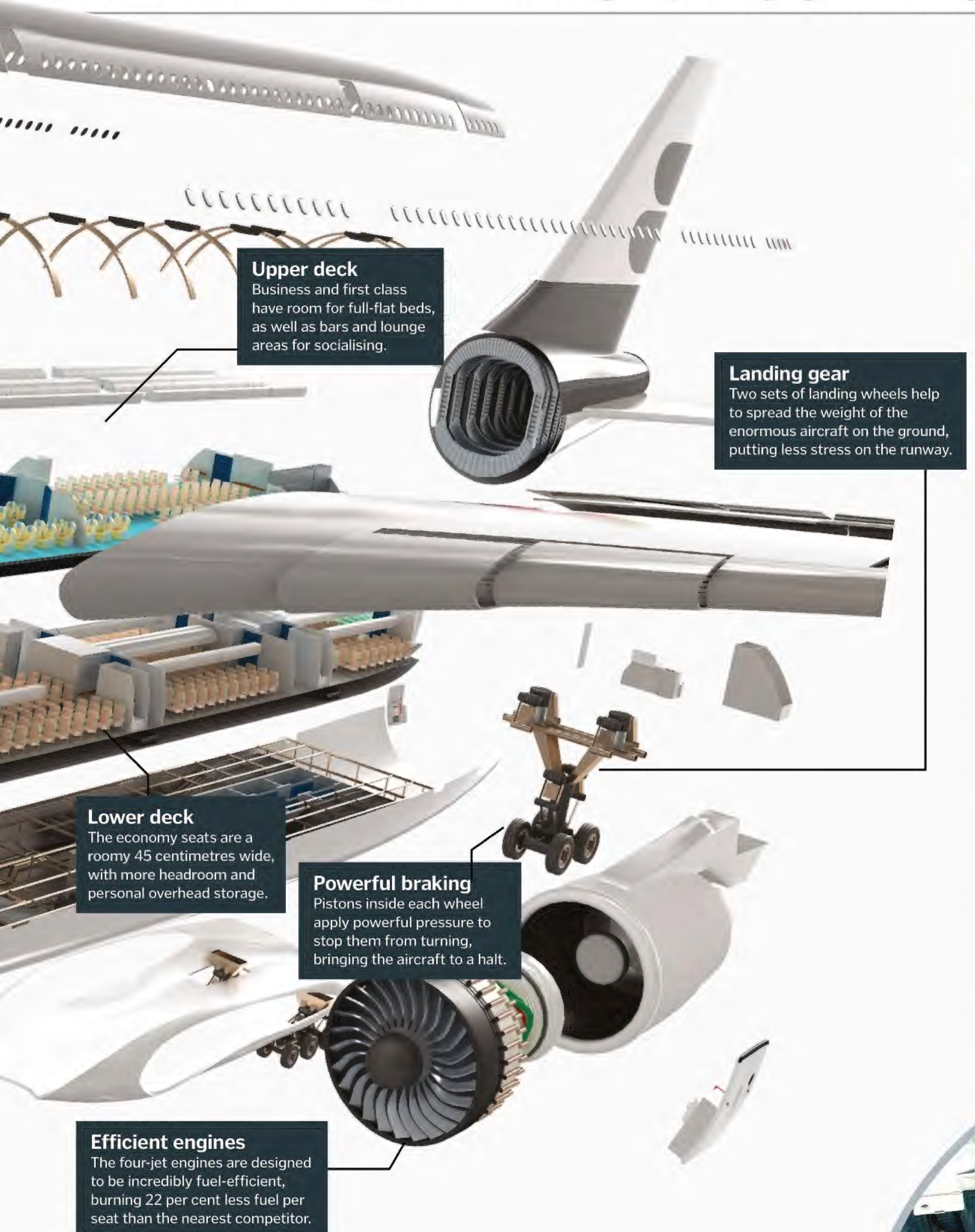
The world's largest passenger jet

How does the enormous double-decker Airbus A380 get off the ground?

Ferrying travellers all over the globe is an expensive business for the world's airlines, so it makes sense that they would want to pack as many passengers as possible onto each aircraft, reducing the number of flights they need to make. Thanks to its double-decker design, the Airbus A380 is capable of carrying up to 853 passengers at a time, if it is in a single-class cabin configuration. That's over 150 more than the aircraft's competitor, the Boeing 747-8. Most A380s, however, feature four separate classes, with economy and premium economy on the lower deck and the more spacious business and first class upstairs, which reduces the passenger number to 544. This is still a 40 per cent increase on the 747-8's four-class capacity.

As well as being the largest passenger jet, the A380 is one of the quietest, with dampeners reducing engine noise to half that of other jets. It is also more environmentally friendly, because it needs to take fewer flights to deliver the same amount of passengers, and the fuel-efficient engines are claimed to give off 22 per cent fewer CO_2 emissions than the jet's closest competitor.

DID YOU KNOW? *The Airbus A380 is covered in three layers of paint weighing around 500 kilograms*



Two staircases provide access to the aircraft's upper and lower decks

Next-gen flight deck

The cockpit of the A380 is designed to be very similar to that of other Airbus aircraft, minimising the amount of time that pilots have to spend training to fly it. It features an instrument panel with eight large, interactive liquid crystal display units showing navigation, engine and systems information, as well as a transparent head-up display that superimposes information over the pilot's view. An electronic library also replaces the traditional paper documentation used by pilots, allowing them to locate operational information more easily and analyse the aircraft's performance.

As the plane prepares for landing, the process is made easier as the flight crew can pre-select the optimum runway exit at their destination airport, and leave the autopilot to regulate deceleration after touchdown accordingly. This helps to reduce runway occupancy time and therefore increase the number of aircraft the airport can handle at any given time.

The A380's cockpit is designed to make Airbus pilots feel at home

Building an aircraft of this enormous size does present a few problems, though. Many airlines have had to modify their aircraft hangars to accommodate the increased height and wingspan of the A380, and some airports just don't have enough space for them to park. Also, to speed up the process of boarding and offloading such a large number of passengers, two gangways from the aircraft to the terminal building are needed – a set-up that only certain airports are capable of.

As a result, the A380 can usually be found travelling to and from the world's biggest international airports, making the most of its 15,200-kilometre range to deliver passengers to far-flung destinations in style.

Solar-powered aircraft

The flying machines that are fuelled only by the Sun

As the search for renewable and carbon-neutral forms of energy intensifies, solar energy is leading the way in fuelling the next generation of aircraft.

One aircraft breaking boundaries in this area is the Solar Impulse 2. This incredible machine is set to launch a non-stop, round-the-world trip powered only by the Sun. It will do this by using 72-metre (236-foot) wide wings, each of which will be carrying over 8,500 solar cells, powering four electric motors and four lithium batteries. Despite this astonishing wingspan, the entire aircraft will only weigh 2,300 kilograms (5,071 pounds), about as heavy as a large great white shark.

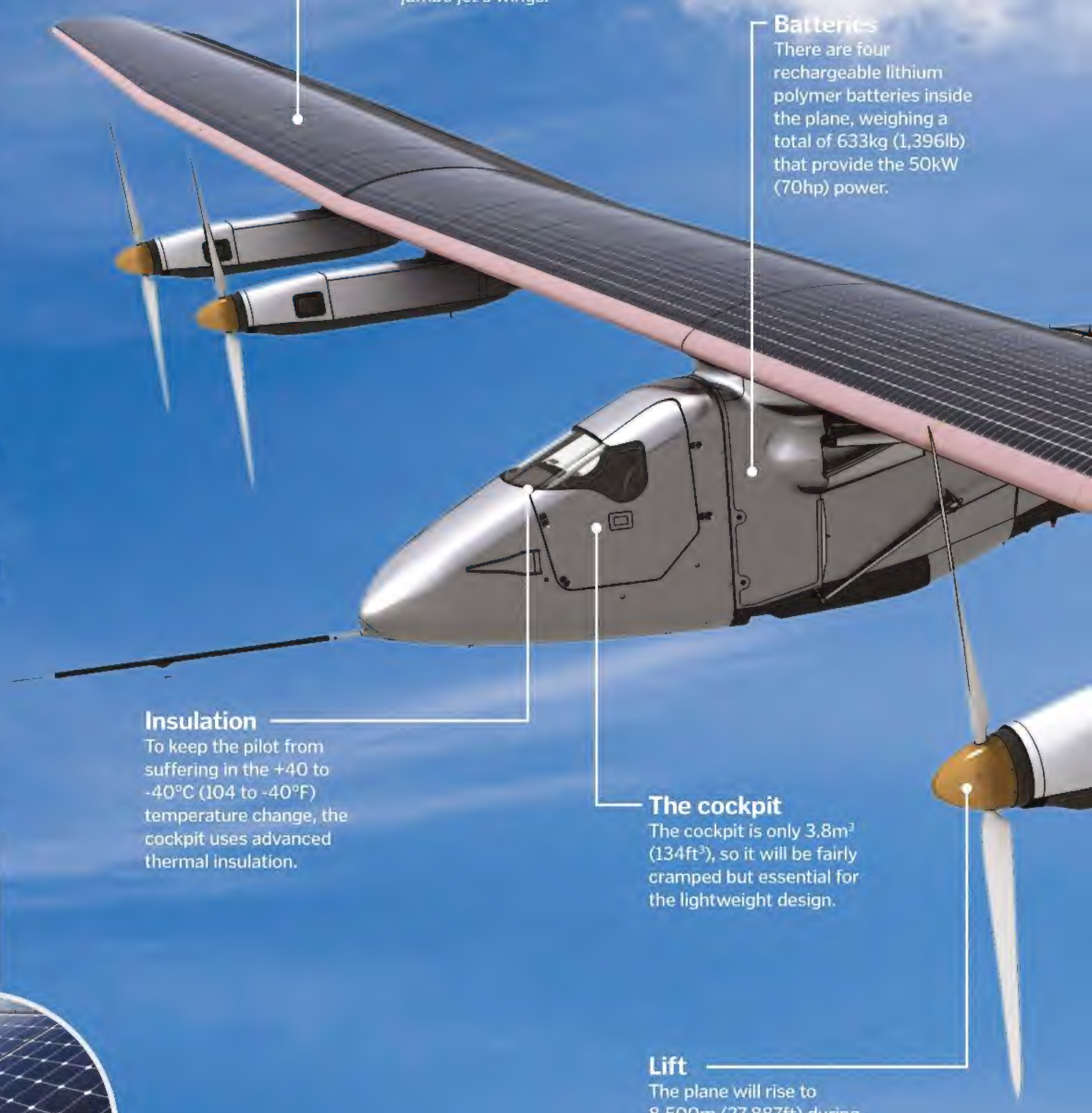
Another major player in the world of solar powered aviation is Solar Flight. Their newest project is Sunseeker Duo, which is the only two-seater solar-powered aeroplane in operation. It follows a similar pattern to the Solar Impulse 2, with long wings covered with solar panels and a lightweight body. Its panels have been improved to become 50 per cent more efficient than their predecessors. It can fly for 12 hours and its engine produces 25 kilowatts (33.5 horsepower) of power.

The main question with using solar power is 'what happens at night?' During the day, not all the energy is used. Enough will be stored in the batteries to allow the aircraft fly at night.

The next challenge for solar-powered aviation is to be able to carry multiple passengers, so hopefully one day soon holidaymakers will be able to use the Sun on their way to soaking it up.

Anatomy of a solar aircraft

How the Solar Impulse 2 gets off the ground and stays there



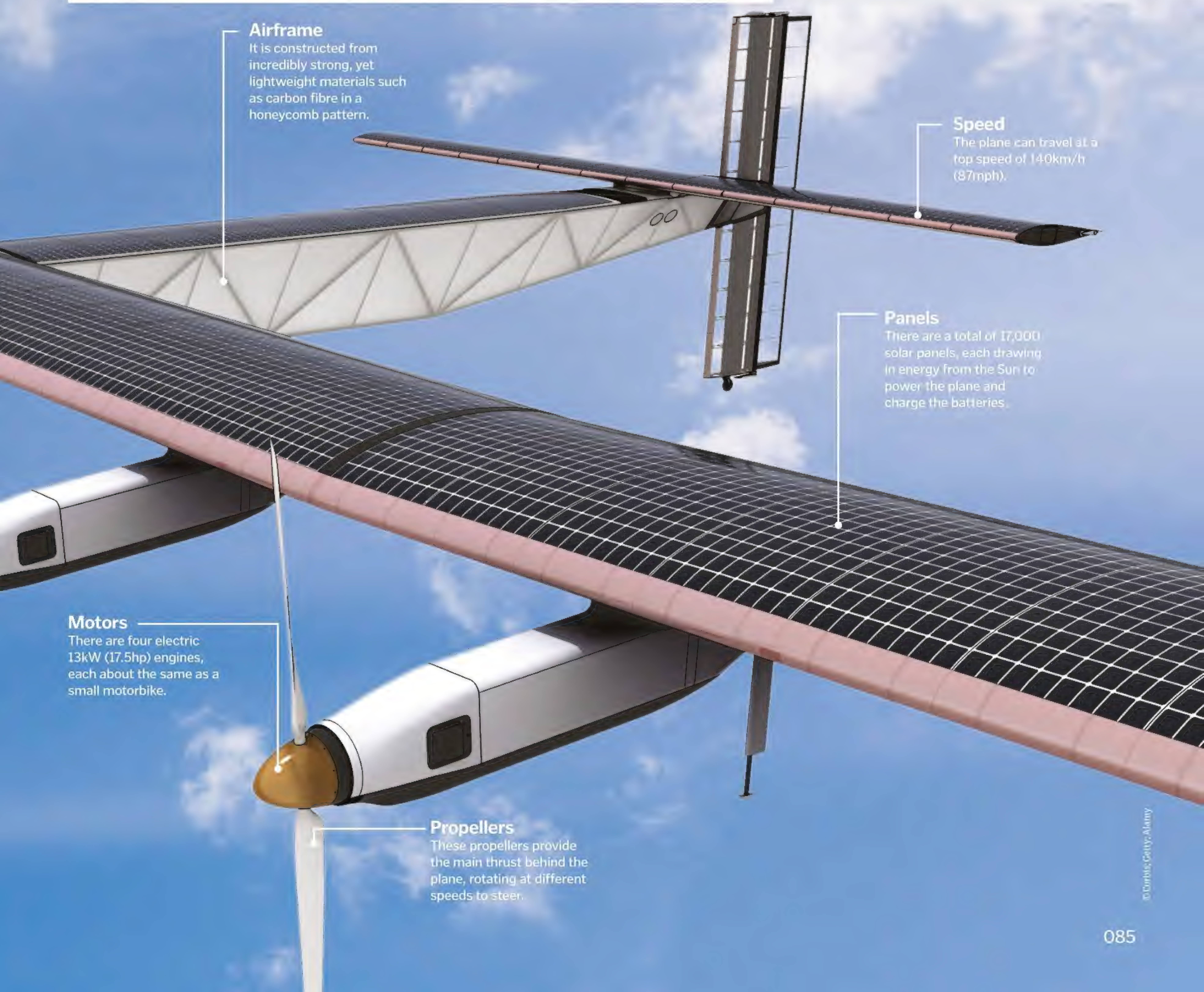
How solar panels work

We have heard a lot about solar panels converting sunlight to energy, but how does that process actually work? Inside a solar panel is a number of silicon cells, placed on top of each other. One of the silicon atoms has all its electrons, while the one beneath it has a few missing. In order to restore the balance, the full silicon atom transfers electrons to the one below, but it needs light to trigger the process. Once the sunlight hits the panel, electrons are transferred from one silicon cell to the other, thus creating an electric current that powers a load.

Despite the massive wingspan, the Solar Impulse weighs about the same as two small cars

Close up power

ESA's Solar Orbiter will be getting a ridiculous boost of solar energy when it takes off in 2017 as its mission is to get closer to the Sun than any probe has before, in order to take incredible pictures of the star. With its 3.1-metre x 2.4-metre (10.2-foot x 7.9-foot) sunshield, this craft will travel just 42 million kilometres (26 million miles) away from the Sun to take high-resolution images and perform experiments. It has been rigorously tested, as it will experience temperatures ranging from 520 degrees Celsius (968 degrees Fahrenheit) to -170 degrees Celsius (-274 degrees Fahrenheit). Its aim is to help scientists lean more about the inner heliosphere and how solar activity affects it, answering questions about solar winds, coronal magnetic fields and solar eruptions.



On board a cargo plane

How do freight aircraft differ from passenger planes, enabling them to transport much greater loads all over the planet?

Cargo planes – whether used in the private, military or commercial sphere – are fixed-wing vehicles that have usually been designed with haulage in mind or have been converted from standard aircraft. Passenger planes commonly have a specialised hold that can store around 150 cubic metres (over 5,000 cubic feet) of freight, found on the underside of the craft. Dedicated freight planes don't need the seats or any of the other amenities on commercial flights – that said, their design amounts to much more than a hollowed-out passenger plane.

To make the most efficient use of the space available, the floor is lined with a walkway and electronic rollers that allow prepackaged pallets to be rolled back as far as possible, without the need for a forklift. Large cargo bay doors are installed to fit bigger items through and, in some examples, like the Boeing 747-400, the nose lifts up to allow particularly large items to pass down the body of the plane. With the demands of air freight ever increasing, aircraft with huge cargo capacities like the Airbus A300-600 Super Transporter (also known as the Beluga), are becoming the norm.

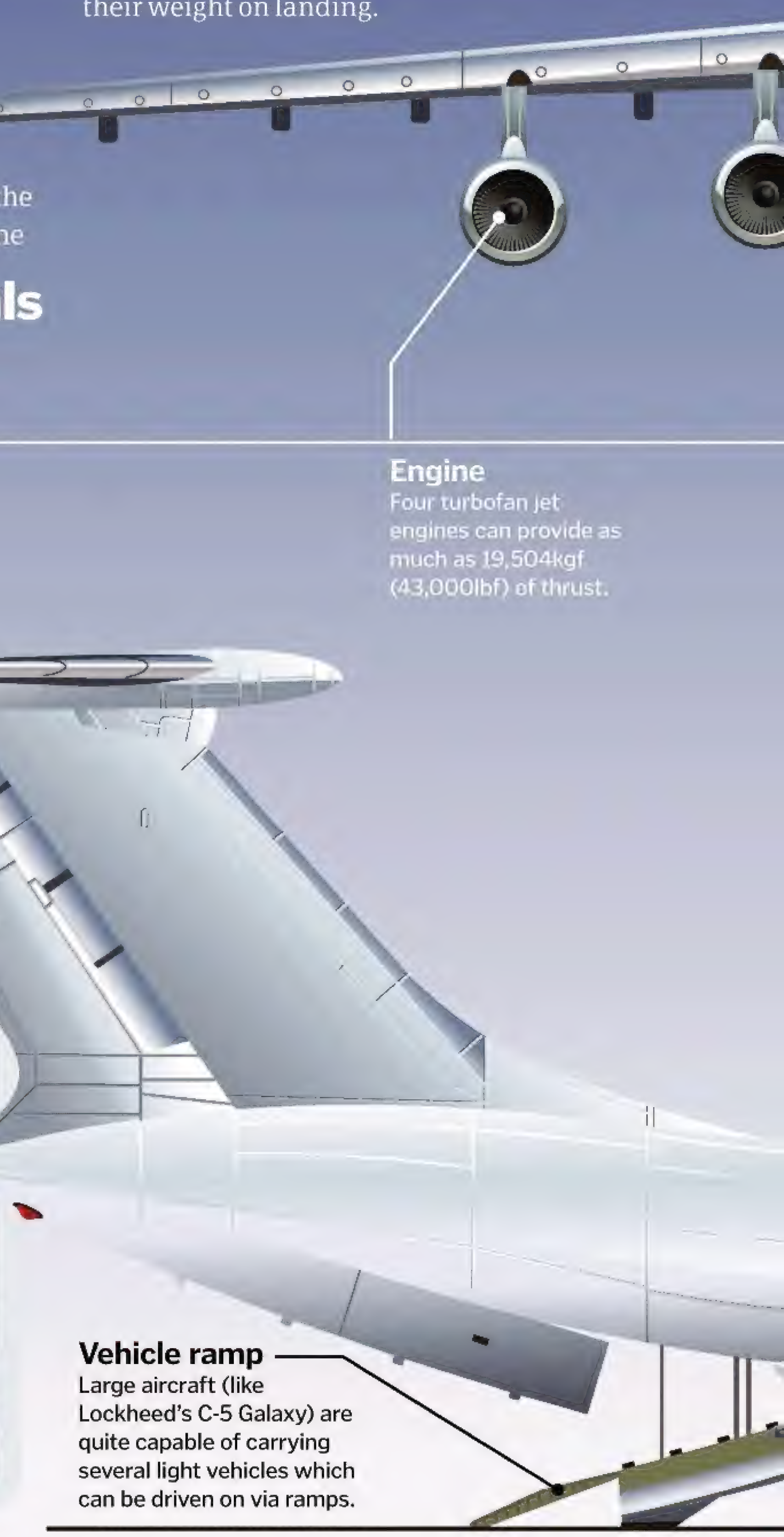
It's not enough just to increase the size of the aircraft hold though. In order for a cargo plane to efficiently and safely transport its mighty load, a number of adaptations must be made to the overall avian design. For example, the wings and tail are built high to allow the freight to sit near the ground and to facilitate loading; the fuselage is much bigger; and – similar to heavy goods vehicles – cargo planes typically feature a larger number of wheels to support their weight on landing.

Plane politics

The Xian Y-20 is a military long-range transport plane that's still in development by China, although it has recently been filmed on a short test flight. It's a similar class of aircraft as Russia's Ilyushin Il-76 or the US Boeing C-17, and though China maintains a tighter guard over its military secrets than most, it has an estimated payload in the region of 72,000 kilograms (160,000 pounds) – that's quite a bit, by any country's standards! The PLAFF (People's Liberation Army Air Force), or avian branch of the Chinese military, had long favoured the development of fighter jets over this kind of support aircraft, so that the Y-20 project was sidelined when it started in 2005. However, following the Sichuan earthquake of 2008, China was unable to effectively drop relief supplies with its small fleet of cargo planes, so the US had to assist with two C-17s. This embarrassment undoubtedly spurred the Chinese government into pushing on with the Y-20's development.

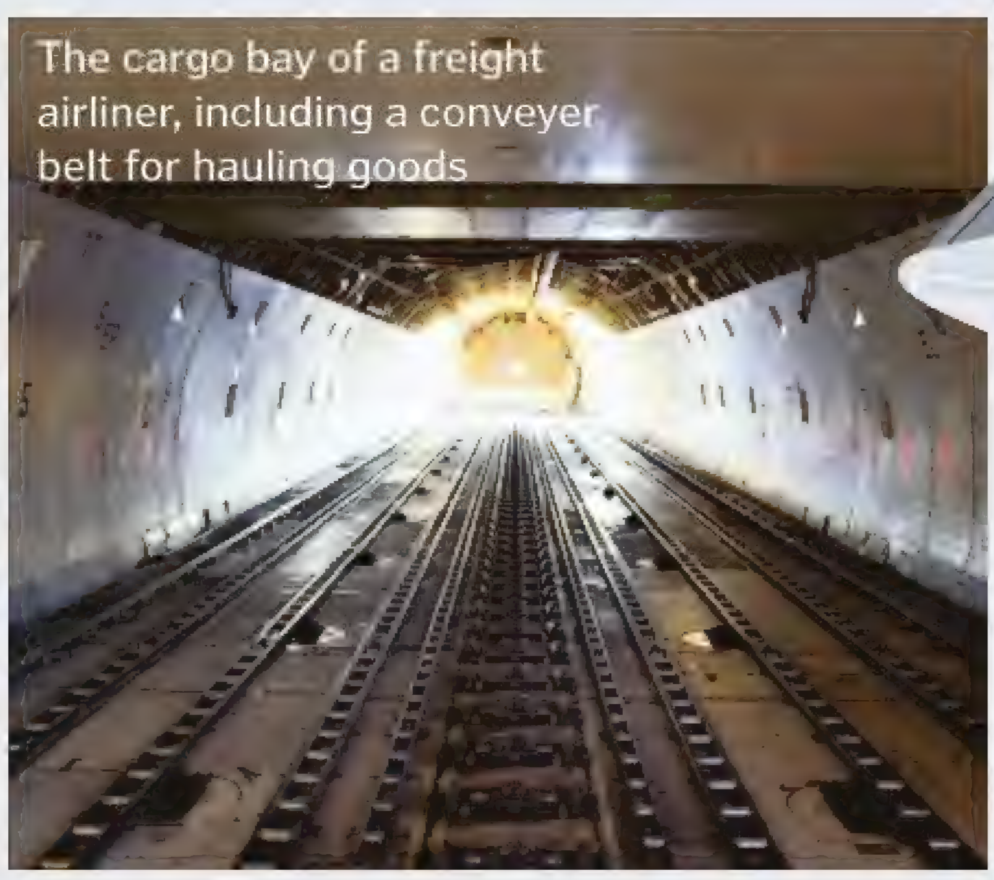
Cargo plane credentials

HIW pinpoints what a military cargo transporter needs to get the job done



Lightening the load

Depending on the type of cargo being carried (very large items or military vehicles may be exceptions), many cargo planes will use ULDs, or unit load devices. These allow the crew to prepackage cargo into single units that can more easily be loaded into the hold prior to the flight, saving a great deal of time. It's a similar system to that used in shipping, maximising the space used at the same time and, thus, increasing efficiency (and profits). The ULDs themselves are either robust and lightweight aluminium pallets or aluminium-floored containers with toughened plastic walls. The containers are sometimes converted into self-contained refrigeration units to store perishable goods.


The cargo bay of a freight airliner, including a conveyer belt for hauling goods

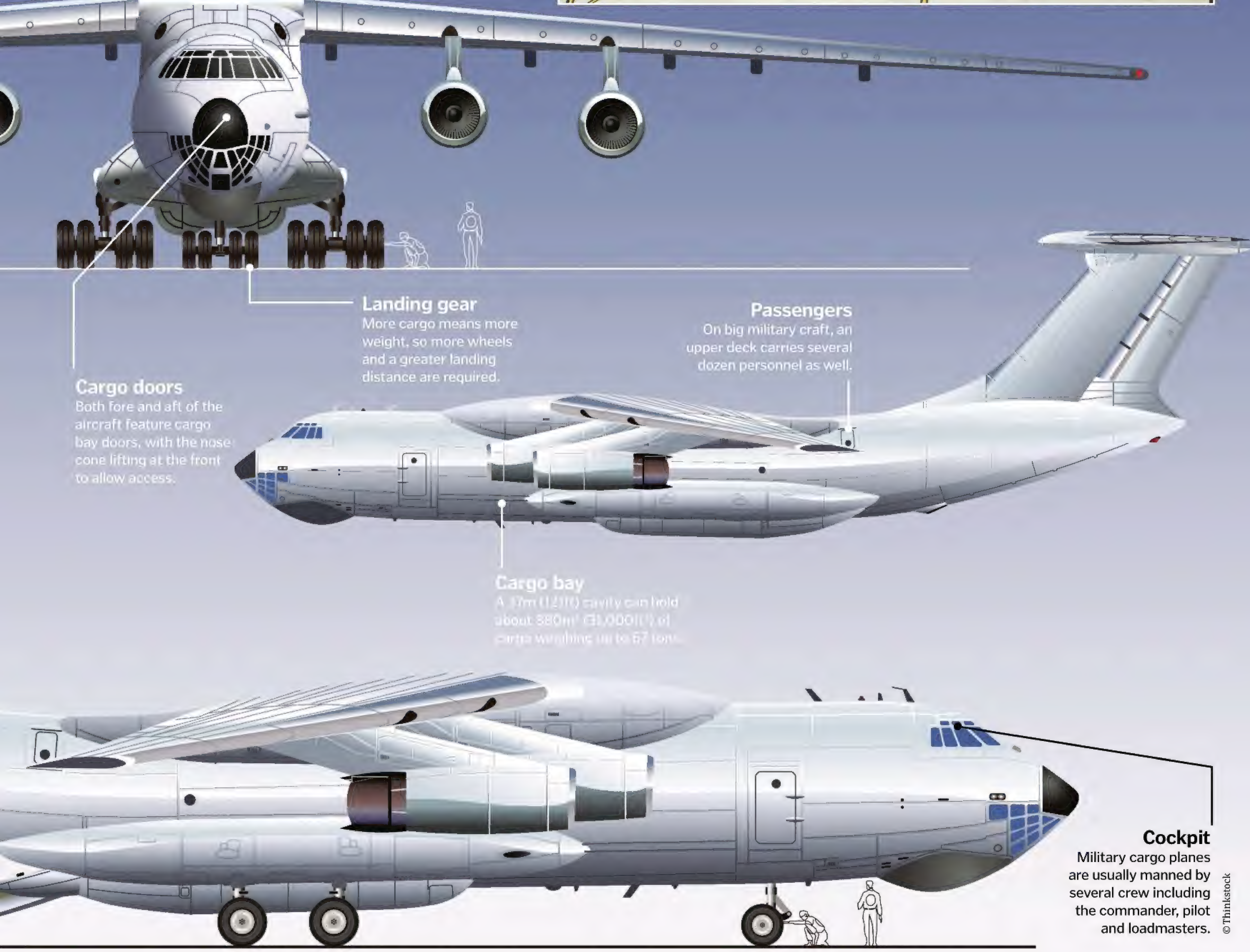
250tons

WORLD'S BIGGEST CARGO PLANE

This title goes to Russia's Antonov An-225 Mriya. It has a wingspan roughly the length of a football pitch, can carry four tanks in its cavernous hold and has space for up to 80 cars.

DID YOU KNOW? Passenger planes have been used to carry mail since 1911 and still do to this day

Lockheed Martin's C-5 Galaxy has 12 internal wing tanks with a total capacity of 194,370l of fuel



Boeing 787 Dreamliner

This new jetliner promises to transform the commercial airliner industry, boasting significantly improved fuel economy and a host of next-gen features. We take a closer look…

At first glance the Boeing 787 Dreamliner appears to be nothing special. A new mid-sized jetliner that through its conventional design, standard power output and modest maximum range seems to, for the most part, blend in with the crowd. Just another commercial passenger jet introduced to a market hit severely by the worldwide recession. A multimillion pound piece of technology that changes nothing. But if you believe that, then you couldn't be more wrong…

That is because, as is common with most groundbreaking new technologies and ideas, the devil is in the details. Indeed, the Boeing 787 is arguably a slice of the future today, both literally (its service life is predicted to extend up to 2028) and metaphorically. The latter comes courtesy of it being the first aircraft to be designed within a mantra of efficiency over everything else. That's not to downplay the aircraft's numerous new improvements and technological advancements in any way – this is one of the most complex jetliners currently in operation in the skies – but in the present financial climate and arguably one that will affect the industry for years to come, this greener, cheaper and more accommodating aircraft is laying down a roadmap that others can now follow. The evidence for this? How about the worldwide orders of 821 new planes from 57 operators to the tune of £93 ($145) billion?

So how is the 787 turning the dream of cheaper, more efficient air travel into a reality? The simple answer is a direct 20 per cent saving on both fuel usage and outputted emissions. The long answer is a little more complicated.

The key to the super-high performance granted by the Dreamliner lies in its adoption of a suite of new technologies and materials. Composite materials (ie carbon-fibre/reinforced carbon-fibre plastics) make up 50 per cent of the primary structure of the 787, which include both the fuselage and the wings. These are lighter, stronger and more versatile than traditional pure-metal offerings. Indeed, when this model is compared against the Dreamliner's predecessor, the Boeing 777 – read: a mere 12 per cent composite materials and over 50 per cent aluminium – you begin to grasp what a game-changer this vehicle is to the jetliner industry.

The new materials have been partnered with a completely revisited build process, which allows each Dreamliner to be produced from fewer aluminium sheets, less fasteners (an 80 per cent

5 TOP FACTS BOEING 787 DREAMLINER

Rollout
1 The Boeing 787 Dreamliner was first unveiled on 8 July 2007 in Washington, USA. By the time of its unveiling it had already accrued 677 orders from companies worldwide.

Big brother
2 The 787 got a big brother in 2013, with a larger – read: elongated – variant of the Dreamliner first in production. This has a capacity for 290 passengers.

Fat boy
3 The initial assembly of the 787 did not go smoothly, with the aircraft coming in overweight by about 2,300kg (5,000lb). Boeing used lighter titanium to reduce this excess.

Assembly
4 Until 2011, the final assembly of all 787s was at the Boeing factory in Everett, WA. Since last year, however, the aircraft have also been put together at North Charleston, SC.

First
5 The first Dreamliner to be officially delivered was to All Nippon Airways in September 2011. ANA is one of Japan's largest airlines, operating to 35 global locations out of Tokyo.

DID YOU KNOW? The Boeing 787 consumes 20 per cent less fuel than the similarly sized 767V

© Boeing


More than 50 companies have worked on the 787, each connected virtually at 135 sites worldwide
© Boeing


787 cabin layouts can be split into one of three configurations, prioritising capacity or class divisions
© Boeing

reduction on the 777) and simpler drill schematics – the latter allowing a 787 to have fewer than 10,000 holes drilled in its fuselage (the 747 needed over a staggering 1 million). This saves on production costs, assembly time and streamlines the build, reducing potential points of failure, while increasing aerodynamic efficiency. In addition, more than 60 miles of copper wiring has been eliminated from the new model, again saving weight, plus streamlining the electrical infrastructure.

Talking of electronics, the Dreamliner has been designed with a state-of-the-art, fully electronic architecture, which through the replacement of all bleed air and hydraulic power sources with electrically powered compressors and pumps, extracts as much as 35 per cent less power from its engines at any one time. Further, a new electrothermal wing ice protection system – with moderate heater mats located on wing slats – improves de-icing levels and consistency significantly, again boosting aerodynamic performance. Wing lift performance is also improved thanks to the adoption of raked wingtips, which reduce the thrust needed by the engines.

These efficiencies combine with the heart of the Dreamliner: its twin next-generation, high-bypass turbofan engines. Two engine models are used on the 787 – both the General Electric GEnx and Rolls-Royce Trent 1000 – each delivering a maximum thrust of 280 kilonewtons (64,000 pounds force) and a cruise speed of Mach 0.85 (1,041 kilometres/647 miles per hour). Both engines are designed with lightweight composite blades, a swept-back fan and small-diameter hub to maximise airflow and high-pressure ratio – the latter, when complemented by contra-rotating spools, improving efficiency significantly. Finally, both engines are compatible with the Dreamliner's noise-reducing nacelles, duct covers and air-inlets. Indeed, the engines are so technologically advanced that they are considered to be a two-generation improvement over any other commercial passenger jet.

As such, contrary to initial appearances, the Dreamliner is really a wolf in sheep's clothing, delivering standard-bearing improvements, along with a vast list of incremental ones – including energy-saving LED-only lighting – that make it one of the most advanced and future-proofed jets in our skies today. And you know what is most exciting? Judging by Boeing's current substantial backlog of sales, there is a high probability that you will be flying on one of these mighty machines yourself in the very-near future.

The statistics...

Boeing 787 Dreamliner

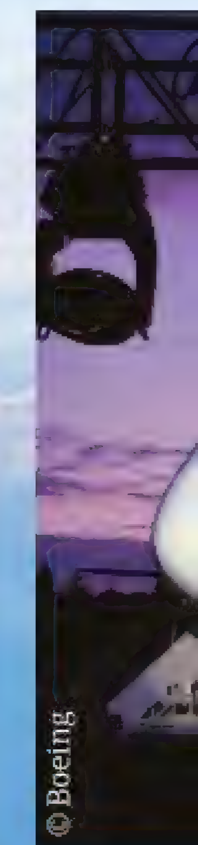
Crew: 2
Length: 57m (186ft)
Wingspan: 60m (197ft)
Height: 17m (56ft)
Max weight: 228,000kg (502,500lb)
Cruise speed: 1,041km/h (647mph)
Max range: 15,200km (9,440mi)
Max altitude: 13,100m (43,000ft)
Powerplant: 2 x General Electric GEnx / Rolls-Royce Trent 1000


A General Electric GEnx high-bypass turbofan jet engine, one of two used on the Dreamliner
© Oliver Cleynen

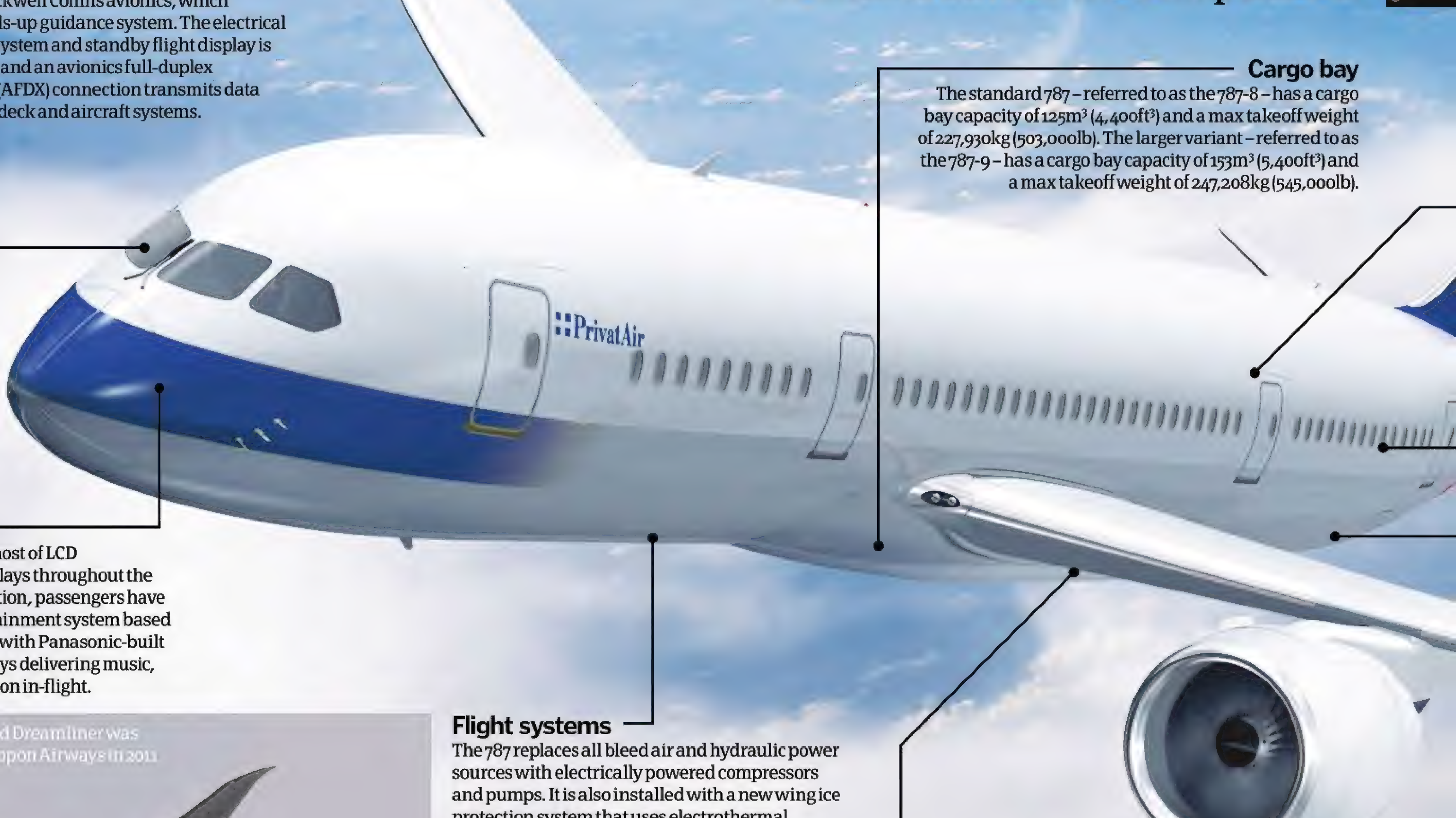
© Boeing

Anatomy of the Dreamliner

We break down a Boeing 787 to see how it outpaces, out-specs and outmanoeuvres the competition



© Boeing



Cockpit
The Dreamliner's state-of-the-art cockpit is fitted with Honeywell and Rockwell Collins avionics, which include a dual heads-up guidance system. The electrical power conversion system and standby flight display is supplied by Thales and an avionics full-duplex switched ethernet (AFDX) connection transmits data between the flight deck and aircraft systems.

Cargo bay
The standard 787 – referred to as the 787-8 – has a cargo bay capacity of 125m³ (4,400ft³) and a max takeoff weight of 227,930kg (503,000lb). The larger variant – referred to as the 787-9 – has a cargo bay capacity of 153m³ (5,400ft³) and a max takeoff weight of 247,208kg (545,000lb).

Electronics
The 787 features a host of LCD multifunction displays throughout the flight deck. In addition, passengers have access to an entertainment system based on the Android OS, with Panasonic-built touchscreen displays delivering music, movies and television in-flight.

The first completed Dreamliner was delivered to All Nippon Airways in 2011

© Boeing

Flight systems
The 787 replaces all bleed air and hydraulic power sources with electrically powered compressors and pumps. It is also installed with a new wing ice protection system that uses electrothermal heater mats on its wing slats to mitigate ice buildup. An automatic gust alleviation system reduces the effects of turbulence too.

Wings
The 787 Dreamliner's wings are manufactured by Mitsubishi Heavy Industries in Japan and feature raked wingtips. The raked tips' primary purpose is to improve climb performance and, as a direct consequence, fuel economy.

Engines
Two engine models are compatible with the Dreamliner: twin General Electric GEnx or Rolls-Royce Trent turbofans. Both models produce 280kN (64,000lbf) and grant the 787 a cruising speed of 1,041km/h (647mph). They are also compatible with the jet's noise-reducing nacelles, duct covers and exhaust rims.

Evolution of the jetliner

We select some of the high points in the development of the commercial jetliner

1945 Vickers VC.1 Viking
A British short-range airliner derived from the Wellington bomber, the Viking was the first pure jet transport aircraft.

1952 DH-106 Comet
The Comet was the world's first commercial jet airliner to reach production. It was developed by the de Havilland company in England.

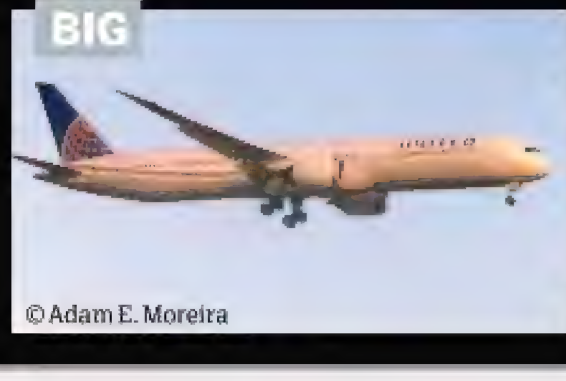
1955 SE-210 Caravelle
The most successful first-generation jetliner, the Caravelle was sold en masse throughout Europe and America. It was built by French company Sud Aviation.

1958 Boeing 707-120
The first production model of the now-widespread 707 series, the 707-120 set a new benchmark for passenger aircraft.

1961 Convair 990
A good example of a narrow-body jetliner, the 990 offered faster speeds and greater passenger-holding capacity.

1976 Aérospatiale-BAC Concorde
A standout development in the second generation of jetliners, the Concorde delivered supersonic, transatlantic flight – something unrivalled even to this day.

BIG



1. Boeing 787-10
The largest Dreamliner, which entered service in 2018, can seat up to 310 passengers when it is configured for highest seat quantity.

BIGGER

2. Boeing 747-400
A significant redevelopment of the 747, the 747-400, when specced out for max number of seats, can carry up to 524 passengers.

BIGGEST

3. Airbus A380
So big that a new term had to be coined in order to classify it – superjumbo – the A380 has two decks and can carry up to a monumental 853 people!

DID YOU KNOW? To date, over 800 Boeing 787 Dreamliners have been ordered by airlines all around the world

A stand-up, fully stocked bar is available on each 787

Amenities
When on board passengers are offered roomier seats (across all classes), larger storage bins, manually dimmable windows, a stand-up bar, gender-specific lavatories and an on-demand entertainment system. First-class passengers receive a complimentary in-flight meal and, on international flights, fully reclinable seats for sleeping.

Cabin
The standard 787 is designed to seat 242 passengers across a three-class arrangement, with 182 seats in economy, 44 seats in business and 16 seats in first. Cabin interior width rests at 5.5m (18ft) and on either side is lined with a series of 27 x 47cm (11 x 19in) auto-dimming windows.

Fuselage
The 787 is constructed from 80 per cent composite materials (carbon fibre and carbon-fibre reinforced plastic) by volume. In terms of weight, 50 per cent of the materials are composite, 20 per cent aluminium, 15 per cent titanium, 10 per cent steel and 5 per cent other.

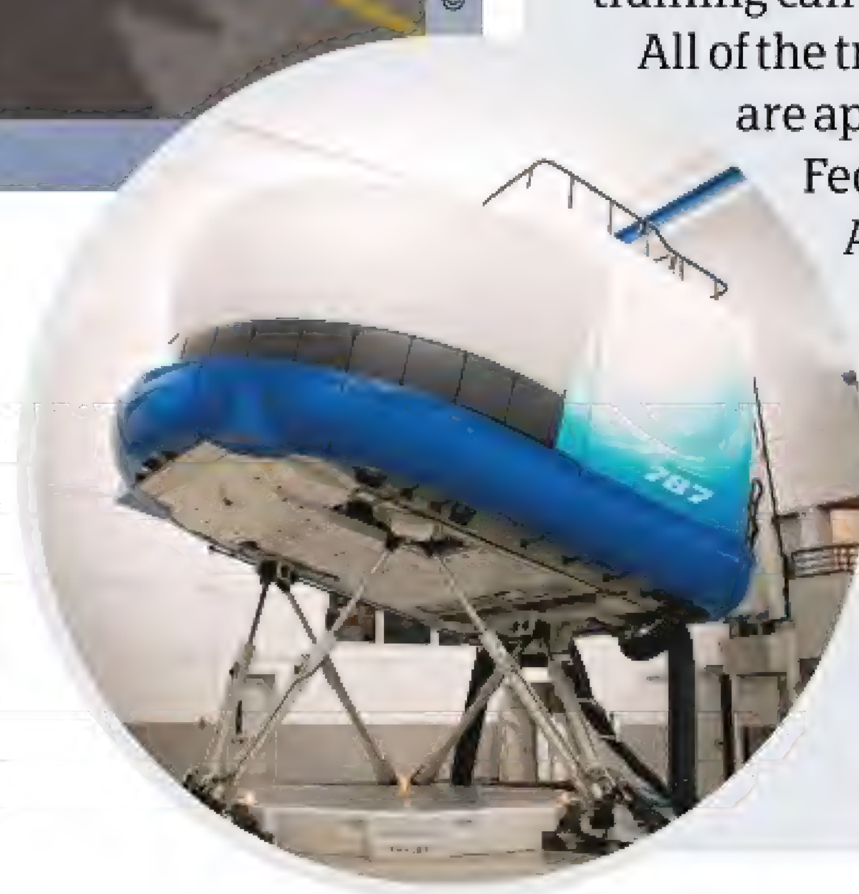
Compatibility
The 787 Dreamliner is designed to be compatible with existing airport layout and taxiing setups. As such the 787 has an effective steering angle of 65 degrees, allowing it to rotate fully within a 42m (138ft)-wide runway. It also has a 32m (100ft) tyre edge-to-turn centre ratio.

Train to gain

Boeing has gone the extra mile to produce a complete package with the 787 Dreamliner, offering state-of-the-art simulation facilities for pilots to get up to speed

Potential 787 pilots can utilise Boeing's revolutionary full-flight simulator to train for real-world flights and specific context-sensitive scenarios. Currently there are eight 787 training suites at five Boeing campuses worldwide, located from Seattle through to Tokyo, Singapore, Shanghai and on to London Gatwick. The simulators, which are produced by French electronic systems company Thales, include dual heads-up displays (HUDs) and electronic flight bags (EFBs), and are designed to train pilots to become proficient in visual manoeuvres, the instrument landing system (ILS) and non-ILS approaches. Further, missed approaches using integrated specialist navigation, non-standard procedures with emphasis on those affecting handling characteristics, plus wind shear and rejected takeoff training can also be undertaken.

All of the training simulators are approved by the US Federal Aviation Administration (FAA), making them officially some of the most advanced training suites around right now.



Pilots and potential pilots can train at eight simulators worldwide

1986 Fokker 100
The Fokker 100 was a short-haul specialist that carried up to 100 passengers. Domestic and short-range international flights were its remit.

1994 Boeing 777
The first computer-designed commercial jetliner, the 777 delivered a vast 300-seat capacity and range (17,370km/10,793mi). It became a mainstay of airlines worldwide.

2005 Airbus A380
Since its launch in 2005 the Airbus has been the largest passenger aircraft in the world. The A380 has two decks and, when specced out for all economy-class seating, can carry 853 passengers.

2011 Boeing 787 Dreamliner
The most fuel-efficient jetliner of its class, the 787 has been designed to reduce the cost of air travel, while delivering a range of next-gen tech.

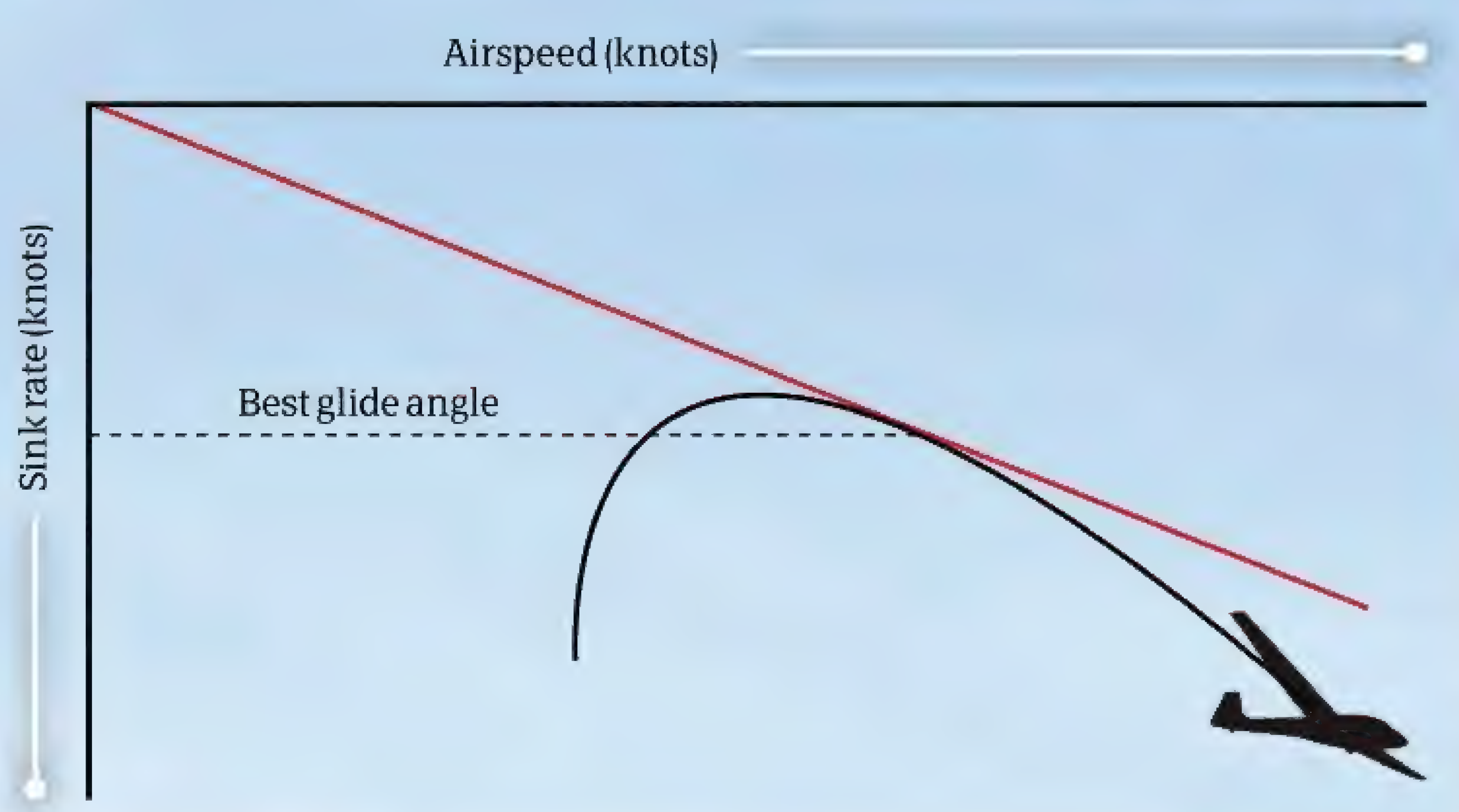
Gliders

How do these engineless aircraft stay airborne?

Gliders work by maximising the dynamic properties of air to remain airborne for long periods of time. To do this they optimise their lift-to-drag (L/D) ratio – the amount of lift generated by a wing or vehicle, divided by the drag it creates by moving through the air – by extending the surface area of their lifting surfaces, ie their wings, streamlining their physical construction and utilising the lightest possible construction materials.

The glide ratio – the distance a glider falls for the distance it travels forward – of any glider is also reliant on its airspeed and the prevalence of rising air in the aircraft's vicinity. For example, if a glider is too light then its fall rate will be low but its travel distance forward will also be low, meaning high speed and long distance glides are impossible, as it will never reach the next area of lift. However, if a glider is weighted correctly, then the polar curve of distance travelled to distance fallen is optimised, carrying the glider between areas of uplift.

A trainer and pupil in a dual-seated trainer glider



> "Weighted correctly, the polar curve of distance travelled to distance fallen is optimised"

5 TOP FACTS GLIDERS

1 Recreational
Modern gliders were developed post World War Two, mainly by enthusiasts just to have fun during their time off work. Back then they were made primarily out of wood, not fibreglass.

2 Tow
Gliders were used in the Second World War to drop soldiers and equipment into war zones. The gliders would be towed half the way and then left to glide to a set drop-off point. They were considered expendable.

3 Cheat
Not all gliders are engineless, with many fitted with one to allow them to take-off on their own, removing the need for them to piggyback on another aircraft in order to get airborne.

4 Boom
The principles of gliding have been extrapolated to the armament industry, where numerous companies make gliding bombs designed to travel great distances without needing any propellant.

5 Training
Many gliders are used by instructors to educate amateur pilots in the basic principles of flight before they are given an engined aircraft. Trainer gliders contain a dual-seated cabin.

The Wright brothers' aircraft without motor in 1911 successfully gliding

Experiments with gliding

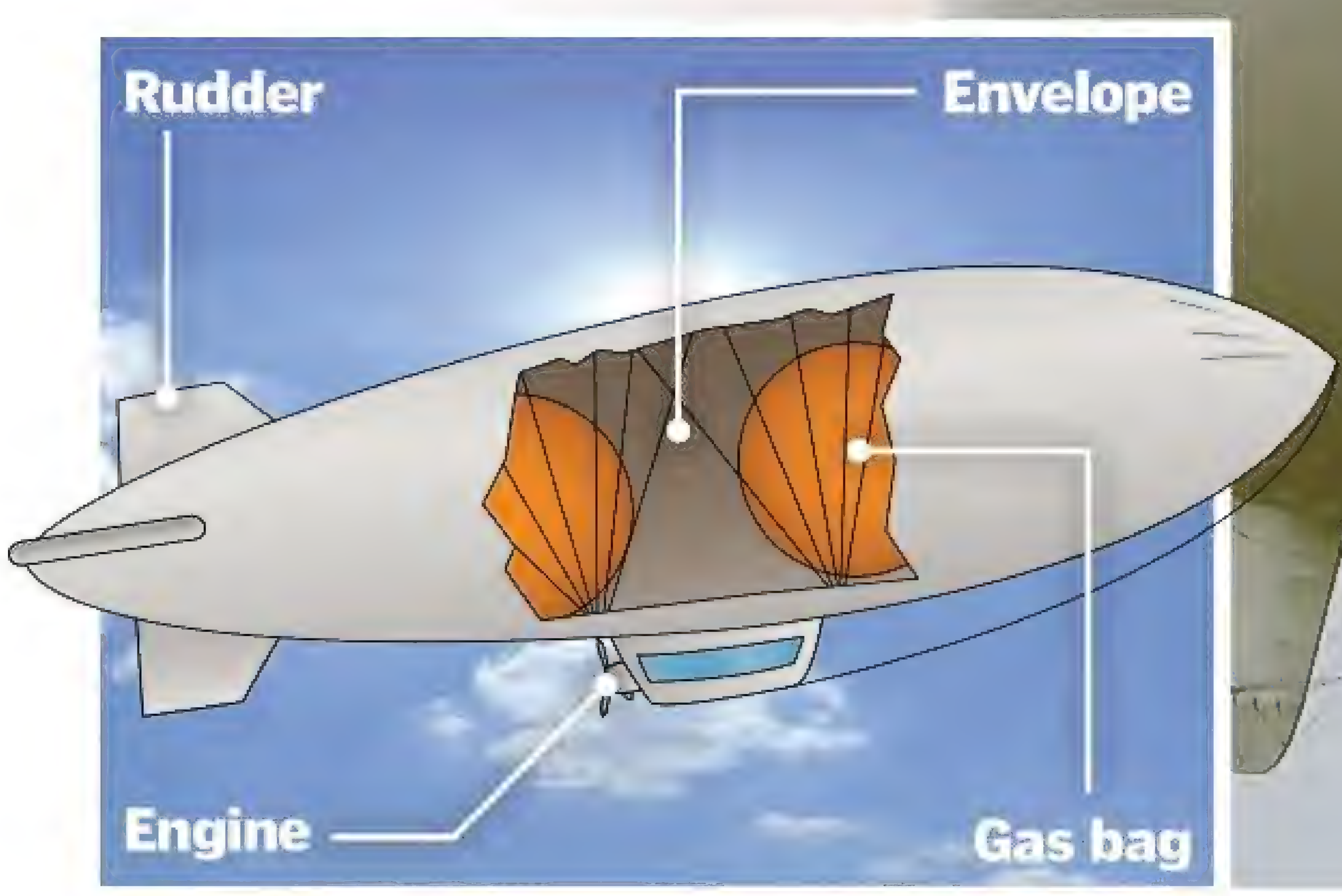
Gliding isn't a new pursuit of humans, although it only reached substantial success in the 20th and 21st Centuries. In fact, the first record of someone attempting to glide through the air occurs in a 17th Century account of a 9th Century attempt by Abbas Ibn Firnas of Cordoba, Spain. Unfortunately for Firnas – who was a respected polymath and inventor – the attempt was reliant on covering himself with vulture feathers and ended in bad back injuries. Where Firnas failed, though, the Wright brothers succeeded, and in 1911 they successfully glided in a modified, engineless variant of their famous aircraft. Since then the engineless glider has evolved into the sleek, streamlined aircraft we see today.

Inside a blimp

Graceful forms of transport that are also often used for advertising and as camera platforms

Blimps keep their shape purely through the pressure of the gas inside their main hull and changes in this pressure are managed by ballonets. These are bags of pressurised air which are also located inside the main envelope and are inflated or deflated to maintain the external shape.

The envelope itself is often made of man-made materials, with Mylar and polyester being common. Within the envelope – the blimp's outer skin – there's a second skin, commonly made from polyurethane, called the bladder. This is where the lifting gas, most commonly helium, is located. The gondola, where the passengers and crew are housed and where the blimp is controlled from, is often made of aluminium to minimise the weight of the gondola and maximise lift. Blimps are best known as platforms for advertising and tend to operate between 300 and 900 metres. However, they can operate up to 3,000m off the ground.



Modern blimps often sport reinforced noses and ducted fans to aid steering

The Perlan Project

How the Perlan II plans to soar to the edge of space

Gliders can soar without the need for engines because of currents of air around the plane that are rising faster than the glider is sinking. A good source of these updrafts is when wind strikes the side of a tall mountain. This creates a standing wave that ripples across the mountain range, and gliders are able to hang in this rising current almost indefinitely.

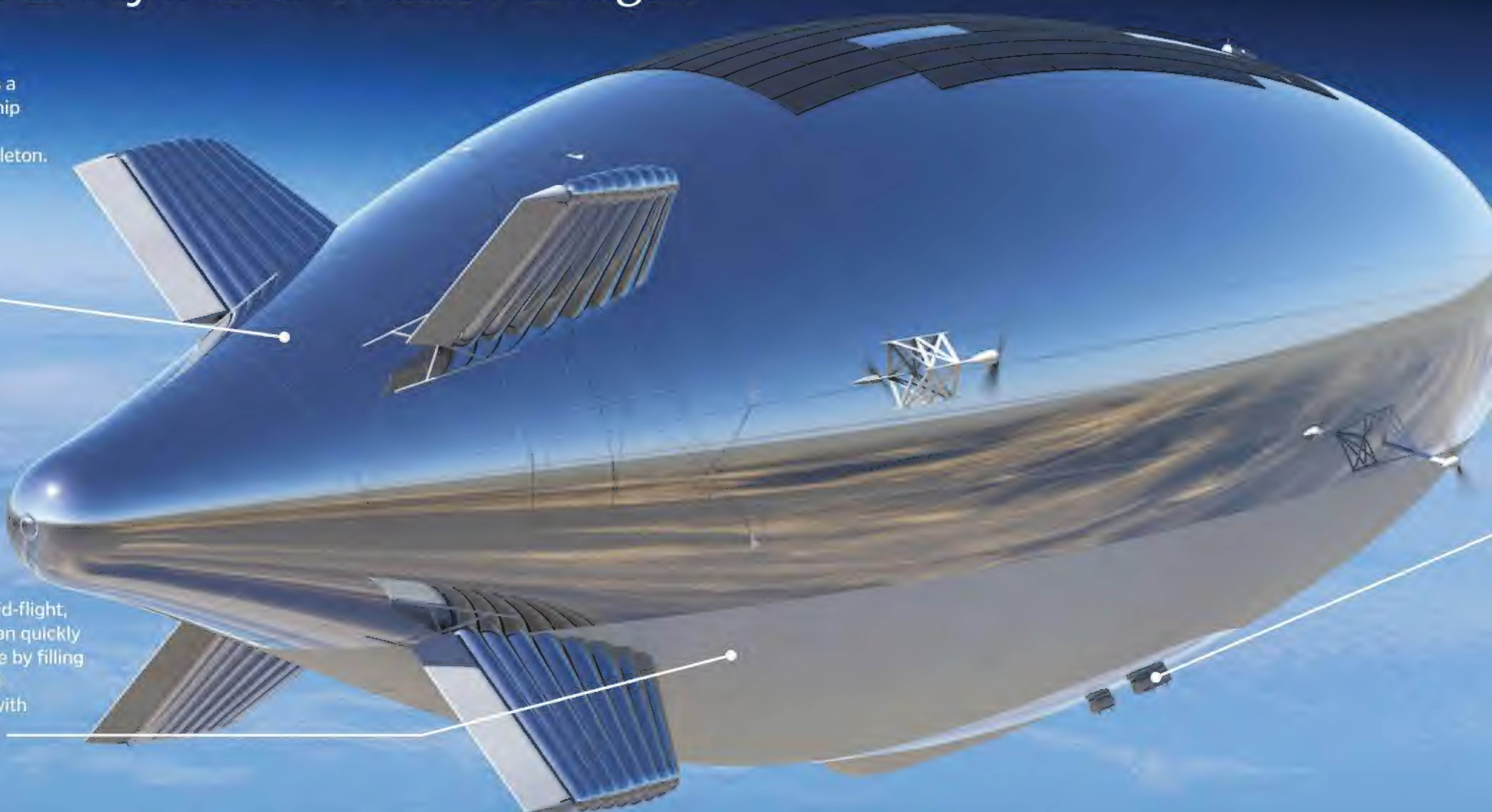
Mountain waves don't normally extend above ten kilometres because winds can't cross the boundary between the troposphere (the lowest layer of Earth's atmosphere) and the stratosphere – the edge of space. But there are a few places in the world where this rule is broken. In the far south of Patagonia, in Argentina, updrafts from the Andes combine in late summer and early autumn with high altitude winds, forming a jet stream known as the polar night jet.

In 2017, the Perlan II, a non-profit research aircraft funded by Airbus, set a new world altitude record for gliding, soaring to over 52,000 feet (15 kilometres). The ultimate aim for the Perlan II, however, is to reach 90,000 feet (27 kilometres), breaking the altitude record for sustained flight previously set by the SR-71 Blackbird spy plane.

The Perlan 2 has a 25.6m wingspan, but weighs just 500kg – less than seven people

How next-gen airships work

Climb aboard these ultra-light giants for a journey into the future of flight



It makes for a breathtaking image: a near-silent goliath of an airship hovering only a few thousand metres above the Grand Canyon or the Norwegian fjords. Inside the airship's roomy accommodations, 200 passengers enjoy their luxury air cruise, a slow but scenic tour of the world's most impressive landscapes.

This is the vision of a new generation of airship engineers and entrepreneurs who believe that dirigibles – rigid-bodied aircraft filled with helium – will be the efficient, eco-friendly transport of the future.

Dirigibles already have a long history. The first manned airship flights were made more than 120 years before the Wright brothers. In the 1780s, French innovators experimented with the first hot-air balloons and hydrogen-filled blimps. In the early days, hydrogen was the preferred gas for lighter-than-air vehicles because it is cheap, plentiful and the lightest substance on Earth – 14 times less dense than air. Unfortunately, it's also highly flammable.

By the early-20th century, German company Luftschiffbau Zeppelin was creating the world's largest and most powerful rigid-bodied dirigibles as both warships and passenger liners. The fiery crash of the hydrogen-filled Zeppelin Hindenburg in 1937, however, effectively burst the golden age of the airship.

Today's dirigibles, inflated with inert helium, fly more like aeroplanes than blimps. These 'hybrid' airships are powered by four or more jet engines that can fully rotate for both horizontal and vertical thrust. In vertical position, the engines are able to lift the airship straight off the ground, eliminating the need for runways. Once up in the air, the rigid, ellipsoid body of the airship also provides aerodynamic lift when cruising.

The combination of buoyancy (helium), vectored thrust (jet engines) and aerodynamic lift (body) results in far greater fuel efficiency than large planes or helicopters. For that reason, airships are being marketed as heavy lifters that can bring 50-500 tons of cargo to remote locations. In ten years, airship designers expect a 200-ton capacity airship to burn 0.1 kilograms (0.22 pounds) of fuel for every 1,000 kilograms (2,204 pounds) of cargo flown one kilometre (0.6 miles). Today, a

RECORD BREAKERS AEROSCRAFT PAYLOAD

60,963kg

THE LIGHTWEIGHT HEAVYWEIGHT

Despite its delicate appearance, the Aeroscraft can actually lift the equivalent of 15 fully grown African elephants (close to 61,000 kilograms/134,400 pounds) in its cargo hold.

DID YOU KNOW? The Hindenburg was designed to fly with helium, but German engineers were forced to retrofit for hydrogen

The statistics...

Aeroscraft

Length: 152m (500ft)
Span: 49m (160ft)
Total passengers: 180
Range: 5,744km (3,569mi)
Cruise speed: 222km/h (138mph)
Altitude: 3,658m (12,000ft)

Introducing the Aeroscraft

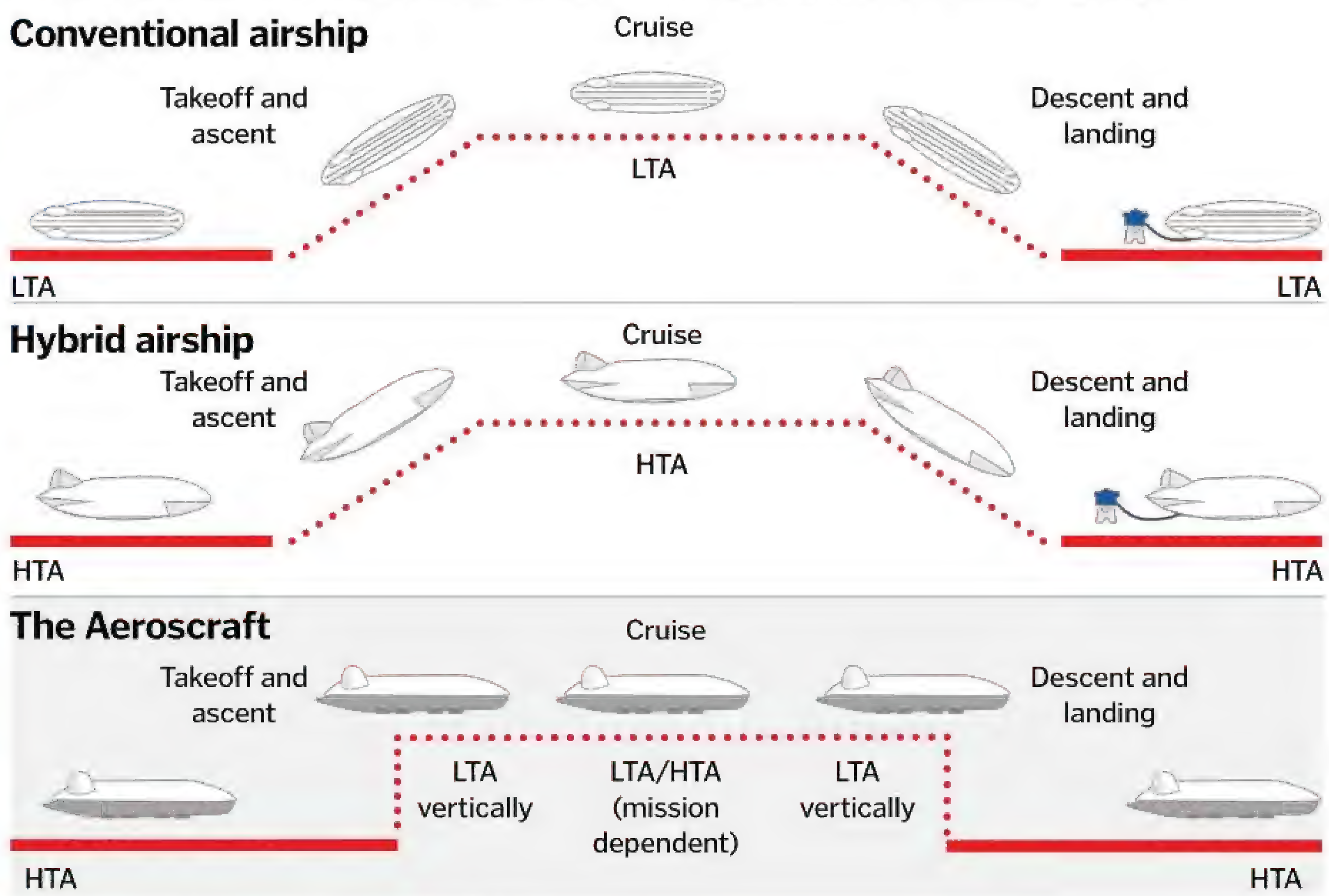
Measuring 152 metres (500 feet) long, luxury liner Aeroscraft will hold 180 passengers as they cruise at 222 kilometres (138 miles) per hour. Travellers can admire the view afforded by floor-to-ceiling windows as the floating giant hovers 3,658 metres (12,000 feet) over the Earth. Aeros describes it as the only next-gen airship capable of truly vertical takeoff and landing; even hybrid airships need a running start to achieve lift. On the Aeroscraft, rapid ascent is powered by a combination of the ship's store of helium and six turbofan jet engines. The difference between Aeroscraft and other airships is an internal ballast system called Dynamic Buoyancy Management. When an airship loads or unloads cargo, the change in weight must be counterbalanced by adding or removing ballast else the vehicle will be too heavy to fly or too light to navigate. Instead of loading and unloading water ballast during takeoff and landing, the Aeroscraft can adjust internal buoyancy by taking in air from the outside and compressing it in internal compartments.

"Today's dirigibles, inflated with inert helium, fly more like aeroplanes rather than blimps"

Hover craft
The Aeroscraft's six powerful turbine engines allow it to hover in place while carrying a full payload, even loading and unloading cargo.

How does Aeroscraft take to the skies?

Compare the Aeroscraft's takeoff and landing abilities with other airships



LTA = Lighter than air HTA = Heavier than air

100-ton capacity 747 jumbo jet burns three times that amount.

A big player in the airship renaissance is the military. The US Army has invested billions in airships as surveillance aircraft and troop movers. Unmanned airships can hover for three weeks at a safe altitude of 6,000 metres (20,000 feet) over targets and airship personnel carriers can take off and land from desert, ice or water.

Within the next 20 years, airship engineers expect to witness a transportation revolution. Green airships will carry drilling rigs to the Arctic Circle. A flotilla of dirigibles will take troops and tanks into warzones. And you and your family may be going on 'sky cruises' on holidays with a whole new perspective.

It's estimated that the Aeroscraft will be able to cross the USA in around 18 hours

Meet the Airlander

The 90-metre (295-foot) Airlander, manufactured by Hybrid Air Vehicles, is a 'hybrid' aircraft with the vertical takeoff agility of a helicopter and the long-range flight capabilities of a conventional airship. Only 40 per cent of the Airlander's lift is supplied by helium. The rest is powered by four turbine engines. This extra muscle enables the football field-sized Airlander to carry payloads of up to 200 tons. The Airlander comes in two models: one for heavy-lift transportation and another for military use. When fully loaded with six 6.1-metre (20-foot) shipping containers, the Airlander can travel 2,500 kilometres (1,600 miles) at a top speed of 160 kilometres (100 miles) per hour. With its vertical takeoff and landing capabilities, the Airlander doesn't require a runway and can land on any reasonably flat surface, including water, snow, ice and sand. The US Army has purchased a fleet of Airlanders for long-range surveillance, both manned and unmanned. On an unmanned surveillance mission, the Airlander can hover above a target zone and provide what the military calls an 'unblinking stare' for 21 days straight without refuelling. The Airlander is marketed as a 'green' transport solution, using far less fuel than conventional aircraft, and supplying a point-to-point solution that eliminates environmentally invasive infrastructure like major roads and airstrips.

Cheap flight
The unmanned surveillance version of the Airlander can fly for weeks on 8,000kg (18,000lb) of fuel costing just £12,600 ($20,000).

Not a blimp
The envelope of the Airlander isn't a blimp-like balloon, but a rigid body formed from a blend of Kevlar, Mylar and Vectran.

ACLS
The air cushion landing system deploys an inflatable cushion to soften landings and provide suction to hold the craft still during loading and unloading.

The statistics...

Airlander

Length: 90m (295ft)
Cruise speed: 148km/h (92mph)
Max altitude: 6,096m (20,000ft)
Max payload: 200,000kg (440,925lb)
Endurance: 21 days (unmanned)
Power: 7,457kW (10,000shp)

Airships like the Airlander will be able to land in terrain that most other aircraft would struggle with

The Hindenburg disaster

The newsreel footage is as powerful today as it must have been on 6 May 1937, when announcer Herbert Morrison choked with emotion as he described the explosive consumption and crash of the LZ-129 Hindenburg, one of the largest (and the last) airships of the era. The exact cause of the fire is unknown – engine backfire, lightning, even sabotage – but the explosion was fuelled by the highly flammable hydrogen gas used to keep the 245-metre (803-foot) dirigible afloat. Incredibly, only 35 people died of the 97 on board.

© Gus Pasquerella

Enter the SkyTug

Lockheed Martin was one of the top competitors when the US Army went shopping for a new surveillance aircraft. In 2006, the Army passed on Lockheed's next-generation P-791 hybrid airship in favour of the Airlander, a similar aircraft built by Britain's Hybrid Air Vehicles and American defence contractor Northrop Grumman. Now the P-791 has been revived as the SkyTug, a hybrid airship poised to serve oil and gas rigs drilling in remote locations. The SkyTug works almost exactly like the Airlander, achieving lift through a combination of helium and fully rotating turbine engines. A Canadian firm recently ordered a SkyTug with a 20-ton cargo capacity, but Lockheed says the design is scalable to handle five times that weight. The SkyTug's air cushion landing system features inflatable landing surfaces that enable the airship to land on almost any terrain, much like its competitor the Airlander. Lockheed is billing the SkyTug as the perfect long-range transport for heavy machinery and equipment. Instead of building expensive roads or railways to Arctic drilling sites, we can now ship heavy equipment via airship. To this end, hybrid airships like the SkyTug can operate in temperatures as low as -56 degrees Celsius (-68 degrees Fahrenheit).

The statistics...

SkyTug

Length: 76.2m (250ft)

Max speed: 148km/h (92mph)

Max altitude: 6,096m (20,000ft)

Endurance: 21 days

Payload: From 20,000kg (44,092lb)

Min temperature: -56°C (-68°F)

The SkyTug was originally intended to be used by the US Army but lost out to the Airlander

Suction
The SkyTug doesn't need to be tied down to a mooring station after landing. The landing system doubles as suction, gripping the ground even in high winds.

Floating freight
Lockheed hopes to launch an entire new industry with the SkyTug: point-to-point shipping of heavy machinery by airship.

Crash proof
If the SkyTug loses all engine power, it won't come crashing to the ground like a lead weight. It will float down slowly and be cushioned by its four inflatable landing pads.

5 TIMES THE SPEED OF SOUND

HYPERSONIC FLIGHT

Inside the planes that will smash supersonic records

DID YOU KNOW? *The crack of a whip is actually a sonic boom – the end of a whip can reach Mach 2*

Blink and you'll miss them, but you'll definitely hear them. Hypersonic aircraft may look similar to the jet planes we're familiar with, but these engineering marvels are completely different beasts. Able to attain speeds that would literally tear a conventional passenger jet apart, hypersonic aircraft possess unique engines, are built from advanced materials and are packed full of intelligent tech.

So just how fast are they? By definition, a supersonic vehicle can move faster than the speed of sound – or Mach 1 – which is 1,235 kilometres per hour, or 343 metres per second. But to be classed as hypersonic, planes must fly at least five times this speed – 6,175 kilometres per hour, or 1,715 metres per second. And their speed isn't limited to Mach 5; that's just the beginning. We've already created aircraft that can reach Mach 20 – that's nearly seven kilometres per second! As long as these vehicles can withstand the pressure in the atmosphere, they can keep moving faster and faster.

For over 30 years we were able to use Concorde to fly at supersonic speeds. It broke through the sound barrier and revolutionised air travel. But now the aim is to go faster than ever, with jets and commercial airliners capable of reaching even greater speeds. This is, of course, no simple task, but little over a century after the Wright brothers first took to the skies, we're still building new and innovative aircraft. This technology reveals new realms of possibility that would make air travel more efficient and convenient than ever before. Imagine travelling halfway around the world in just a few hours, or seeing a spacecraft climb into the upper atmosphere without a gigantic rocket.

The most exciting part is that this isn't the stuff of science fiction – we've already flown vehicles at hypersonic speeds, and researchers are now developing hypersonic planes suitable for public use. Read on for more of these incredible feats of engineering and the faster world that awaits us.

> *"Hypersonic aircraft attain speeds that would tear a conventional passenger jet apart"*

Hypersonic vs supersonic

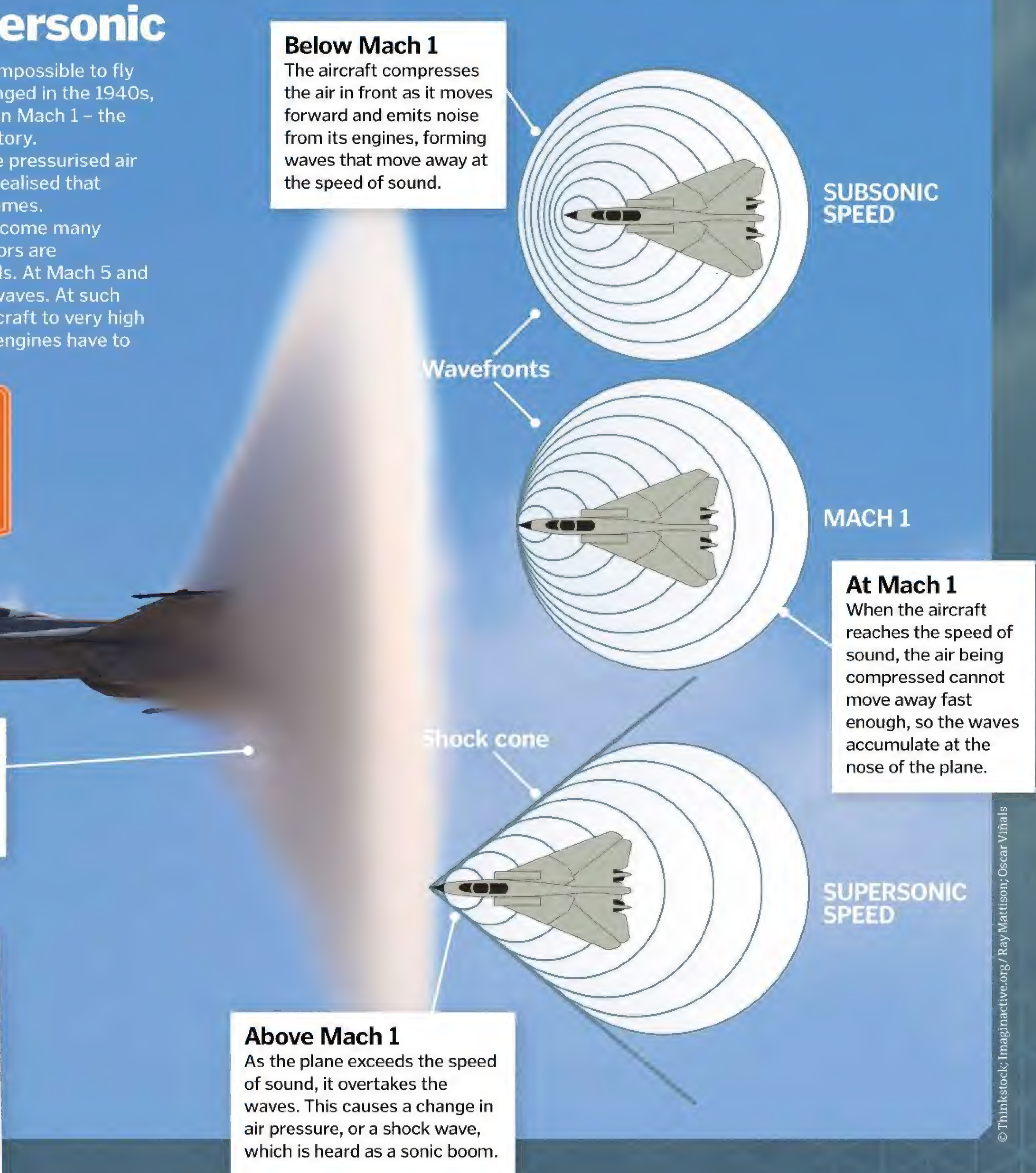
For many years experts believed it was simply impossible to fly faster than the speed of sound. But that all changed in the 1940s, when US test pilot Chuck Yeager flew faster than Mach 1 – the speed of sound – for the first time in human history.

Onlookers below heard the sonic boom as the pressurised air gave way to the Bell X-1 rocket plane, and they realised that supersonic aircraft were dealing with new extremes.

But although supersonic aircraft have to overcome many obstacles to break the sound barrier, these factors are compounded when moving at hypersonic speeds. At Mach 5 and above, the air does more than just form shock waves. At such high speeds, the air heats the surface of the aircraft to very high temperatures – enough to melt steel – and the engines have to cope with huge pressures.

What causes a sonic boom?

Why breaking through the sound barrier is such a noisy affair



Around 75 passengers could be transported at Mach 10 inside the Skreemr

BUILDING A HYPERSONIC VEHICLE

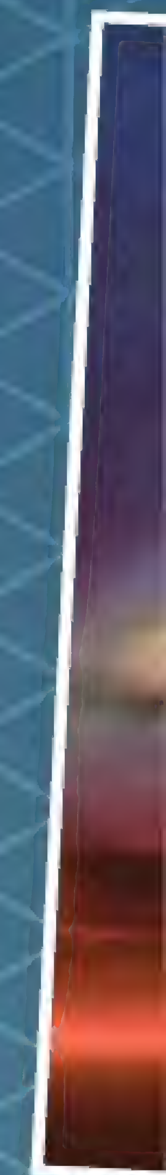
The challenges and successes in the engineering community's quest for hypersonic flight

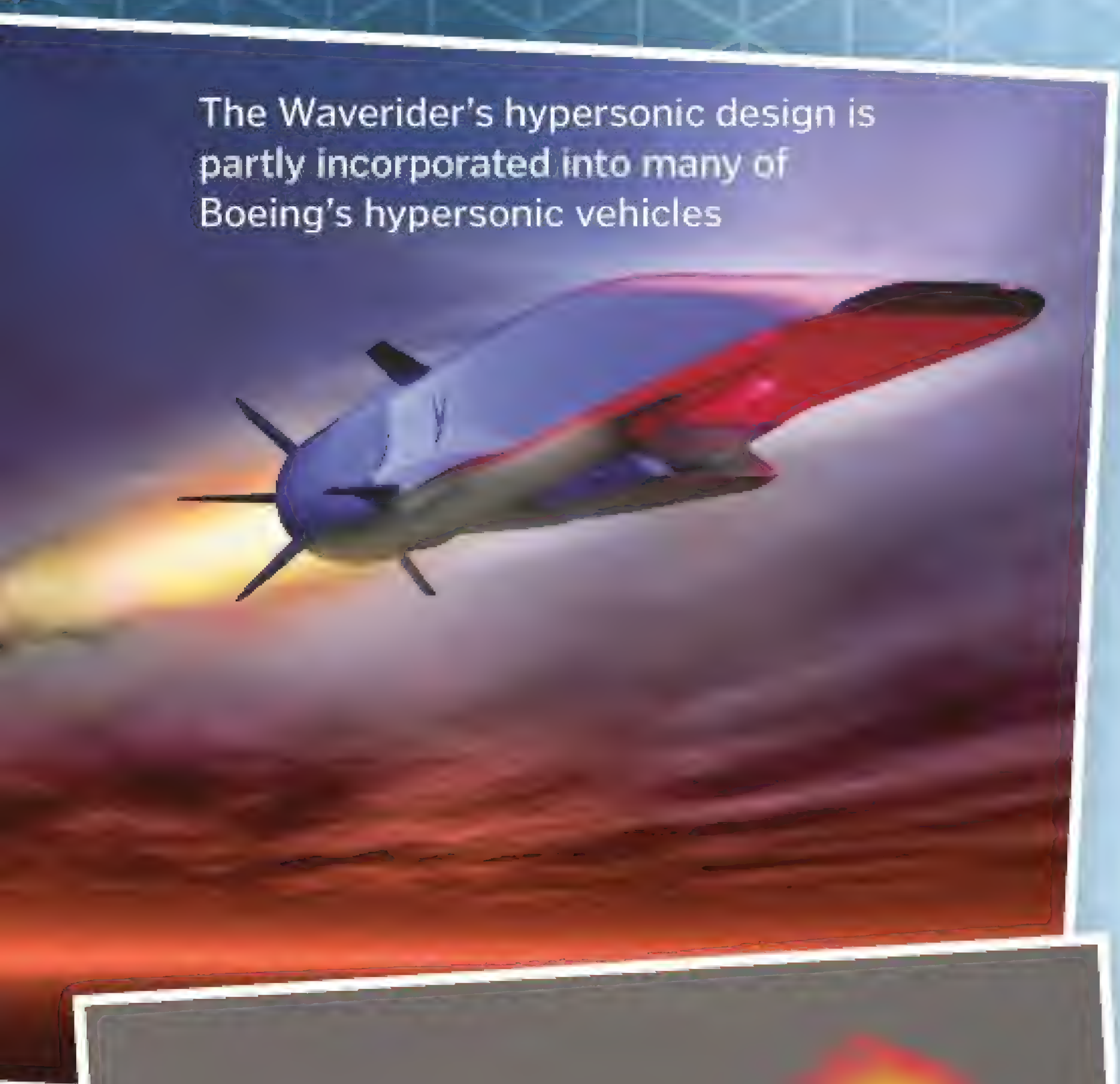
Supersonic aircraft such as Concorde differed greatly from their subsonic counterparts. They had adapted wing designs and advanced engines. These changes allowed Concorde to smash through the sound barrier, which is something subsonic commercial jets were simply unable to do.

The difference between a supersonic and a hypersonic aircraft is even more striking, because at hypersonic speeds the rules change completely. The previously benign air starts to become a serious problem, as aircraft moving at hypersonic speed generate huge amounts of friction. This results in temperatures hot enough to melt the frame of a standard jet, so hypersonic aircraft must be built from robust heat-resistant materials such as ceramics. And they can't stop there, because even if they are able to withstand the heat, the pressure at low altitudes is simply too great to fly at hypersonic speeds. Hypersonic vehicles need to climb high up into the atmosphere, where the air is much thinner, in order to lessen the strain on the aircraft.

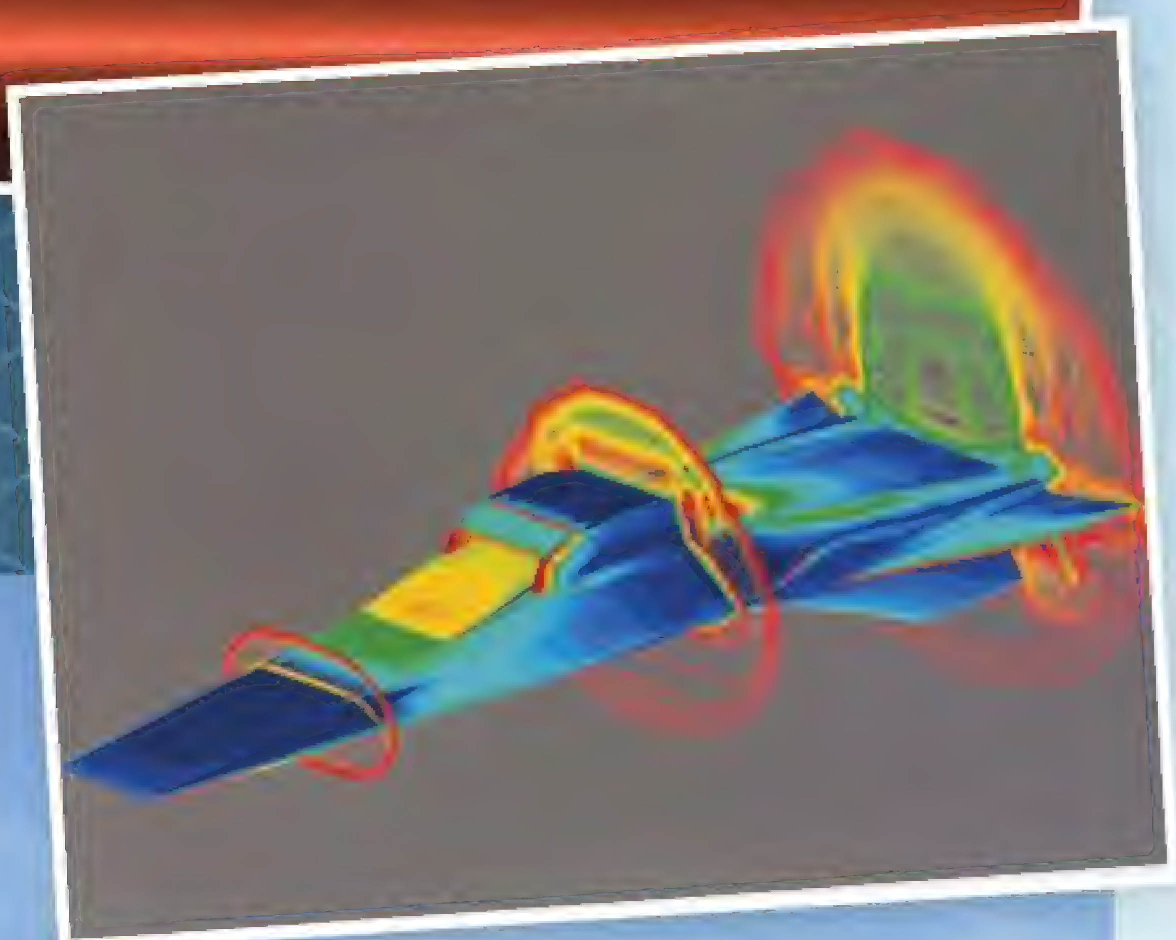
Perhaps the biggest consequence of the intense airflow is that hypersonic vehicles can't even use the same engines as subsonic aircraft. Air moving through supersonic plane engines does so at subsonic speeds (the supersonic airflow is slowed by an engine inlet), but if you tried using a similar setup when travelling at hypersonic speeds, it would melt or simply explode before your eyes. But rather than rely on rocket engines – the only proven systems to power hypersonic vehicles – engineers asked themselves a more ambitious question: could we take what we've learned about the jet engine and design an equivalent that works at high supersonic, and even hypersonic, speeds?

This led to the invention of the supersonic combustible ramjet, or scramjet. Taking the principles of a jet engine and stripping away all of the unnecessary components for hypersonic travel – such as a turbine and a compressor – allows air to move through much more quickly. With few moving parts, these simple-looking engines produce enough thrust for an aircraft to soar at incredible speeds; and in doing so, have started to bring the future of air travel to life.





The Waverider's hypersonic design is partly incorporated into many of Boeing's hypersonic vehicles



The X-43 was the first aircraft to travel at Mach 7, enduring 1,650 degrees Celsius in the process

MAKING HYPERSONIC FLIGHT A REALITY

We spoke with Boeing's chief scientist of hypersonics, Dr Kevin Bowcutt, about the future of high-speed travel

Dr Kevin Bowcutt is the senior technical fellow and chief scientist of hypersonics at Boeing. He is an AIAA Fellow, a Fellow of the Royal Aeronautical Society, and also a member of the National Academy of Engineering. He holds BS, MS and PhD degrees in aerospace engineering from the University of Maryland, US.

Why is Boeing so interested in the hypersonic technology?

Boeing is interested in hypersonic technology for several reasons, including application to missiles, aircraft, and space planes. Hypersonic airplanes may someday whisk passengers and cargo across oceans in an hour or two, enabling international day trips. Perhaps most exciting of all, reusable hypersonic space planes may make transportation to Earth's orbit more like flying in an airplane than a rocket, and therefore much more affordable – up to 100- times cheaper.

What hypersonic technologies are you currently developing?

Key enablers to make hypersonic flight a reality include lighter and more durable high-temperature materials, increased hypersonic engine efficiency, and advanced sensing and data analysis technologies. On the technology front we are developing advanced high-temperature ceramic matrix composite materials, structures, and thermal protection systems. We are also developing, and have applied, advanced hypersonic vehicle design methods based on multidisciplinary design analysis and optimisation (MDAO). We have designed, and continue to study, hypersonic vehicle concepts such as missiles, reconnaissance aircraft, passenger airplanes, and reusable launch vehicles (space planes). We have built and successfully flown two scramjet-powered experimental vehicles, the NASA X-43A and the USAF/DARPA X-51A.

What are the main challenges that you currently face?

Finding materials that withstand very high temperature,and that are lightweight and durable, remains a challenge, although good progress is being made in their development. Scaling up scramjets to larger sizes (beyond small jet engine size in terms of air flow rate) and speeds above Mach 7 is another difficulty due to ground testing limitations. Integrating low-speed and high-speed propulsion systems into combined cycle engines is another area for further development; combined cycle engines are required to accelerate from zero to hypersonic speed. Additional challenges include vehicle thermal management and thermo-structural health monitoring, as well as designing highly integrated systems such as hypersonic vehicles, driving the need for MDAO. On top of this, adequate funding is a perennial problem, although the situation is improving.

What is the overall goal of your project?

While Boeing is not developing a hypersonic airliner, and does not see a near-term demand for the product, we continue to research many advanced hypersonic concepts and technologies, so that we are prepared if the market develops for such vehicles. The potential for hypersonic aircraft in the future will require further advances in several areas of technology, as well as market demand. Ultimately, we want to help create the future of flight: ultra-rapid global transportation and routine and affordable space access.

How do you personally picture the future of hypersonic flight?

Although it's likely to be a few decades away, I envision a future where Mach 5 airplanes fly people between international cities in a couple of hours, and space planes routinely fly people to a hub in Earth's orbit for connecting flights to the Moon or Mars. Eventually, these vehicles will be powered by clean, high-density energy, probably some form of safe nuclear power.

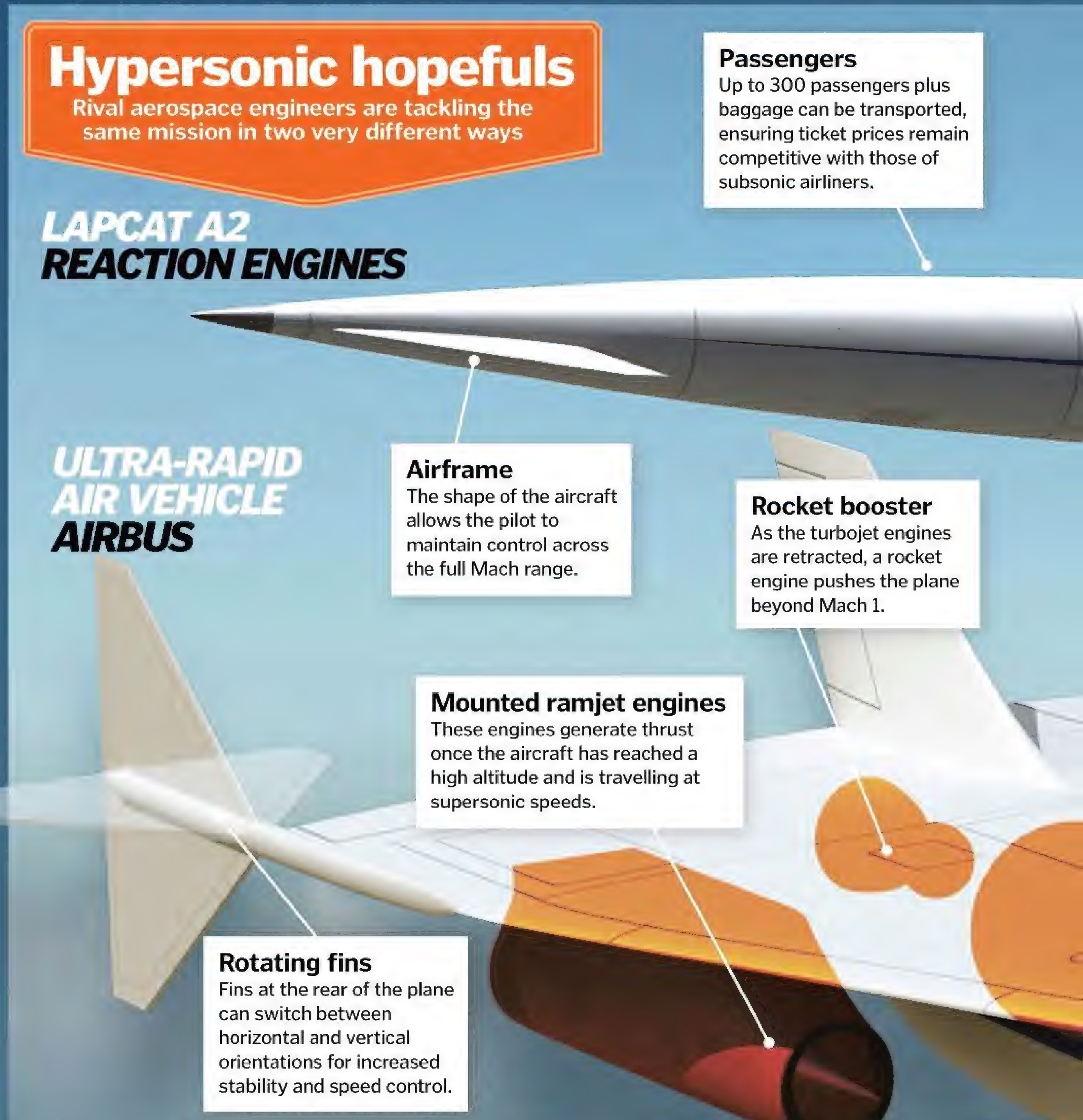
THE FUTURE OF HYPERSONIC FLIGHT

Exploring the concepts that could one day replace the jet plane

If there's one lesson that we've learned about hypersonic flight so far, it's that heat, weight and power are all major obstacles. Too much weight, and you can't reach the desired speed. Too much heat, and your aircraft will melt mid-flight. And then there's the question of how we can power our machine to hypersonic speeds and keep it there. Fortunately, solutions for each of these critical problems have been suggested – and some seriously cool aircraft have been designed in the process.

Innovative engineers such as Charles Bombardier have been at the forefront of these endeavours. His envisioned aircraft, called Skreemr, would take to the skies with the help of an electrical launch system such as a railgun – so we could be bidding farewell to runways one day. A railgun is an electromagnetic strip that uses electricity to launch projectiles at incredible speeds, and could be used to fire the Skreemr into the air. This would eliminate the need for tons of extra rocket fuel for take-off, reducing the aircraft's weight considerably.

Another design by Bombardier, known as the Antipode, could tackle the heat problem as well as the menacing sonic boom. By using counter-flowing jets of air that move outwards in front of the aircraft, the temperature generated from aerodynamic friction and the sound produced by the sonic shock waves would be significantly reduced. And these features would help the Antipode fly up to Mach 24, equivalent to 29,500 kilometres per hour! These designs are still some time away from being realised, but Airbus and Reaction Engines have recently generated two concepts that could have us cruising at hypersonic speeds that much sooner.

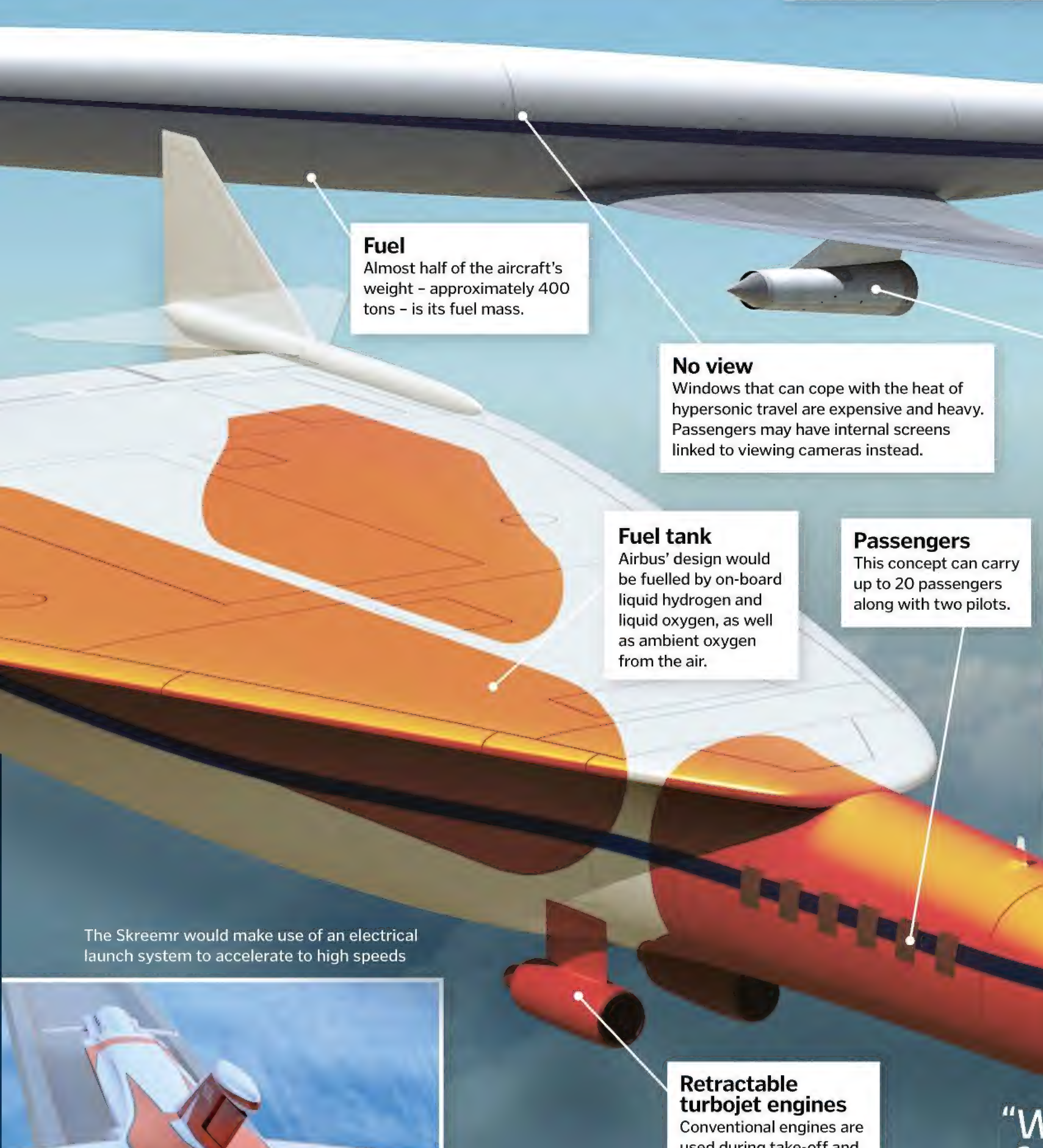


The history of hypersonic travel

It's been 60 years since a piloted vehicle first travelled faster than Mach 5, breaking the hypersonic barrier in a defining moment that showed the true possibility of space travel. The X-15 aircraft not only showed us that we could be carried at hypersonic speed, but taught us about how best to design, control and safely land a vehicle capable of achieving such a feat. The aircraft itself was essentially a rocket/plane hybrid, built to endure temperatures up to 700 degrees Celsius and fly at an altitude of over 100 kilometres, while being blasted through the air by a rocket engine at the rear.

Its achievements filled its creators with confidence that they could soon launch a vehicle into space at high speeds and bring it back into the atmosphere safely. Essentially, the X-15 played a role in putting humans on the Moon.

The legendary X-15 was the first vehicle to carry a pilot at hypersonic speeds



Two passengers would be able to reach the other side of the world in under an hour in the Antipode

The Skreemr would make use of an electrical launch system to accelerate to high speeds

"We could be bidding farewell to runways one day"

HIGH-SPEED HOLIDAYS

It may soon be possible to watch the Sun rise in Paris and set in Tokyo

Most of us see travelling to the other side of the globe as the trip of a lifetime. Aside from the expense, these journeys take a very long time indeed. When we have to watch hours upon hours of in-flight entertainment on long-haul flights, it feels like we're lumbering through the air.

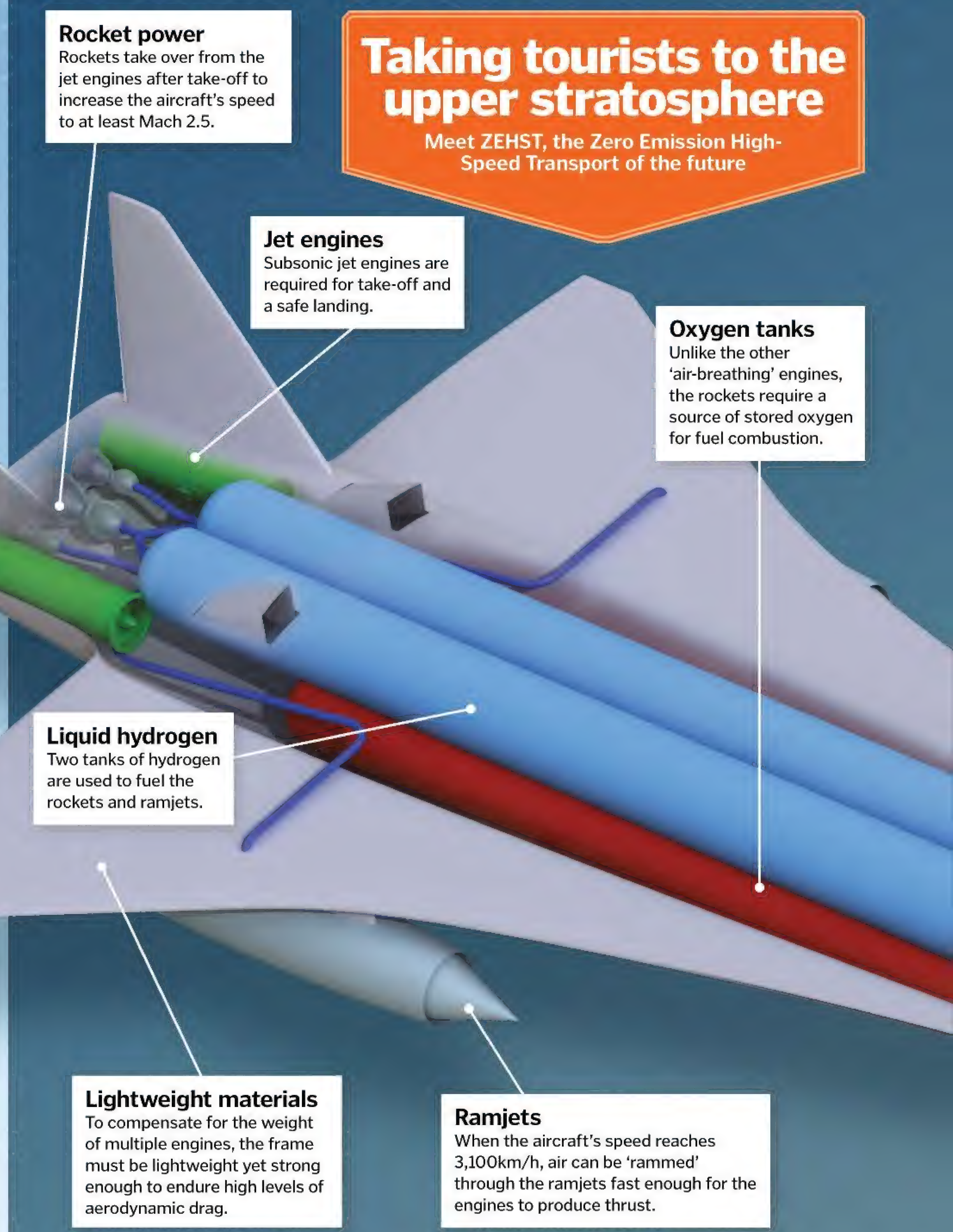
Ever since the world lost Concorde in 2003 we've been content to fly within the sound barrier. But the answer to our travel woes could be to punch right through it and go faster than any passenger plane has before. By flying at the upper limits of supersonic speed and into the hypersonic speed region, we could dramatically reduce travel times and change the way we explore the world.

The unique design of the aircraft has become the main challenge for revolutionising air travel. Most passengers probably wouldn't be comfortable strapping into a rocket and blasting across the planet. Using a rocket for international travel would also be unfeasibly expensive, complicated and bad for the environment. Ideally, the hypersonic passenger carrier of the future will operate much like today's subsonic airliners. Passengers would be able to take their seats in a pressurised cabin, and the vehicle would be able to take-off and land unaided on a conventional runway.

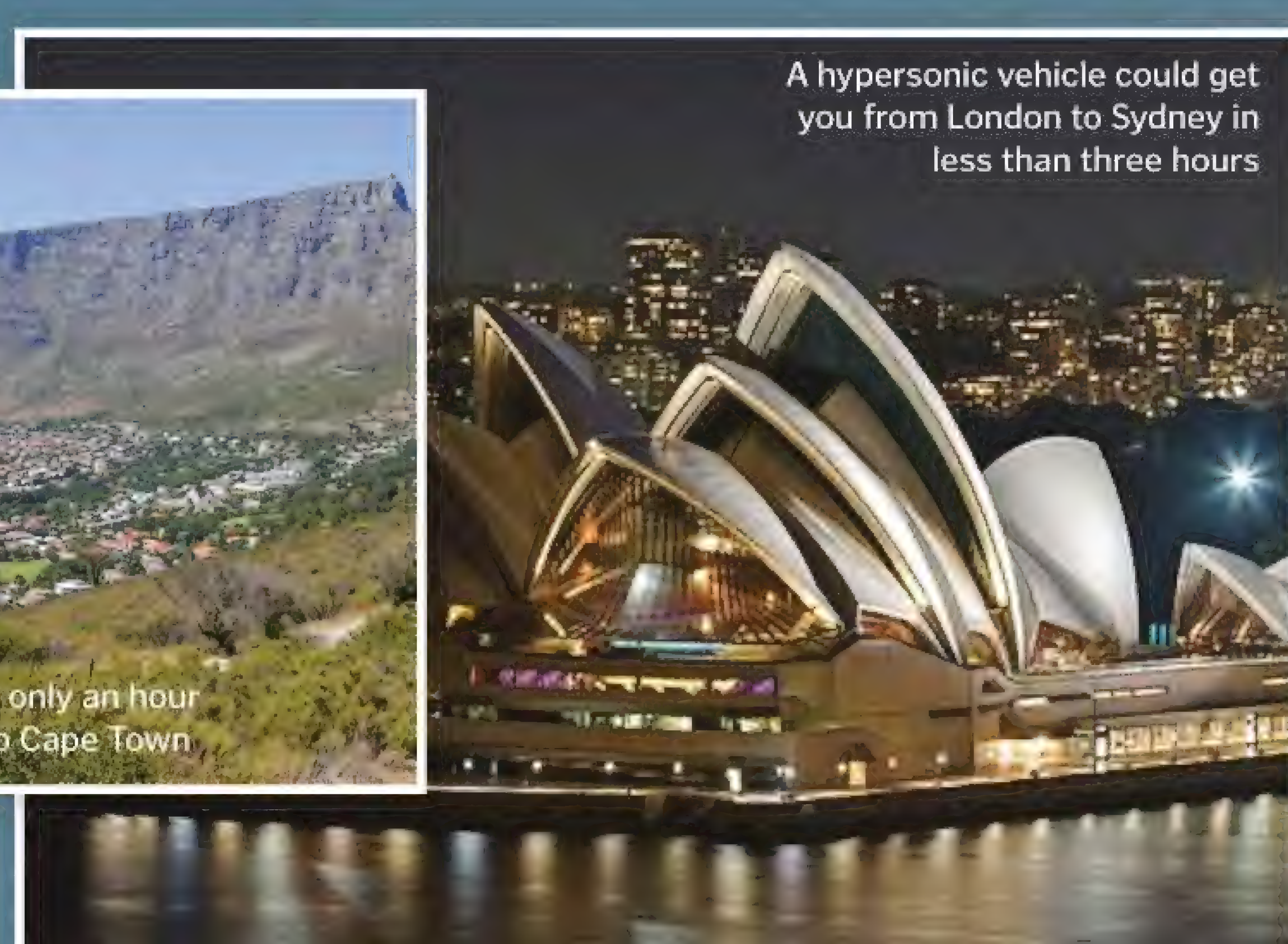
Engineers have decided that using multiple engine types is the way to get this technology off the ground. Typical jet engines could be used for take-off and landing; a rocket engine could then propel us to great heights and speeds; and then the supersonic or hypersonic engine could take over. This would nevertheless be something of a thrill ride, as some designers believe their aircraft would have to take off near vertically! Those of us with a nervous disposition to flying may find it best to stick to the relatively sluggish speeds of a jumbo jet. However, for those holidaymakers and businesspeople who want to maximise the time spent at their destinations, and are willing to brave a vertical ascent into the atmosphere, hypersonic journeys will be the way forward.

Taking tourists to the upper stratosphere

Meet ZEHST, the Zero Emission High-Speed Transport of the future




It would take a hypersonic vehicle only an hour and a half to travel from London to Cape Town


A hypersonic vehicle could get you from London to Sydney in less than three hours

Suppressing the sonic boom

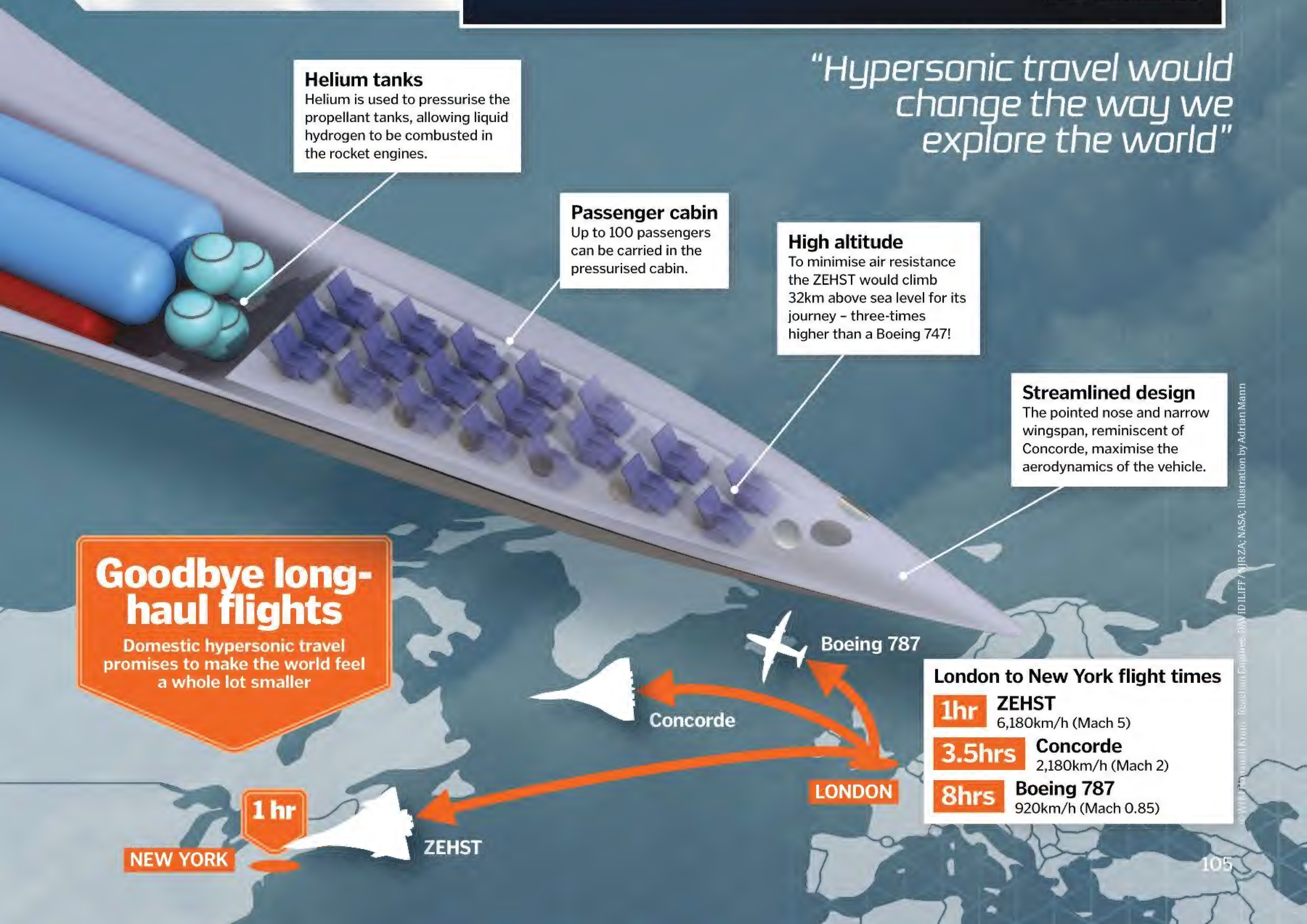
Whether you're going supersonic or hypersonic, breaking the sound barrier is loud. As a vehicle accelerates, the waves of air pressure being pushed along by the frame begin to merge into one single shock wave. This air can travel at the speed of sound but as a vehicle surpasses this speed, a drastic change in pressure results in a deafening clap – a sonic boom.

The sonic boom is one major hurdle for aviation companies to overcome if hypersonic flight is going to be made available commercially. Concorde – the first and only public transport to break the sound barrier – was criticised for its volume and was only permitted to break the sound barrier over the ocean.

Like many aerospace issues, it could be NASA that comes to the rescue once again. The space agency and its partners at Lockheed Martin are in the process of designing an aircraft with many lifting surfaces to stop the airwaves from combining. The result would be a series of small booms rather than one big one – lowering the sound output to that of a normal conversation.

NASA and Lockheed Martin's Quiet Supersonic Technology (QueSST) X-plane design will be a step towards 'low-boom' supersonic travel

"Hypersonic travel would change the way we explore the world"



Goodbye long-haul flights

Domestic hypersonic travel promises to make the world feel a whole lot smaller

London to New York flight times

1hr	ZEHST	6,180km/h (Mach 5)
3.5hrs	Concorde	2,180km/h (Mach 2)
8hrs	Boeing 787	920km/h (Mach 0.85)

HOW IT WORKS BOOK OF AIRCRAFT

Spacecraft

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"In just five decades, space travel has truly come on leaps and bounds, and will continue to develop"


118


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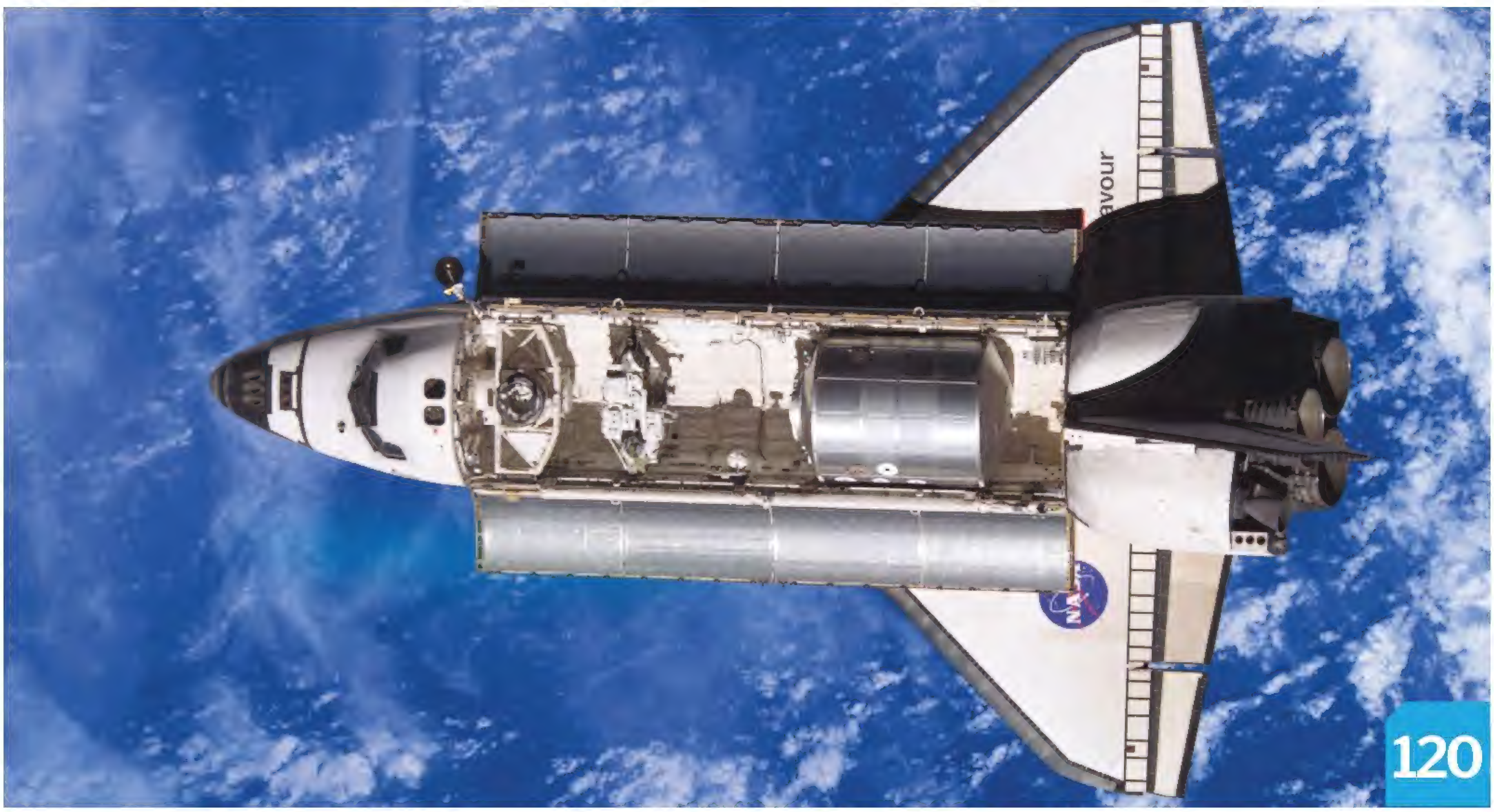
Virgin
116


avour
120

THE SPACE SHUTTLE

How this marvellous vehicle ferried astronauts to and from orbit for 30 years

DID YOU KNOW? *Space Shuttle missions were labelled to avoid the number 13 because of a NASA superstition after Apollo 13*

On 12 April, 1981, the Space Shuttle launched into our skies for the first time as the orbiter Columbia lifted off from Cape Canaveral, Florida. This mission, STS-1, was the first in what would be 135 successful missions in 30 years of service. Two tragedies — Challenger in 1986 and Columbia in 2003, both of which lost their crews — overshadowed the programme in its later years. But the achievements of the Shuttle were many.

The Space Shuttle was born from a desire to make space more accessible. Following on from the expensive race to the Moon with the Soviet Union, the Shuttle was NASA's attempt to get back on more steady footing. After the US emerged victorious by landing on the Moon in 1969, President Richard Nixon wanted a new direction for NASA. They began to develop the Space Shuttle, a reusable method to reach orbit at what was hoped to be a lower cost.

Originally, NASA had planned the Shuttle to be a fully reusable two-stage vehicle, both piloted on their way to space. Budget cuts, however, led to a still impressive but decidedly clunkier design of the shuttle that did not quite live up to the dream of reusability. The Shuttle launched strapped to a giant tank of fuel, with two side solid rocket boosters (SRBs) attached to give it an extra kick. The orbiter itself was reusable and could land on a runway, but the tank was expendable and the boosters had to be recovered from the sea, where they were damaged by salt.

Despite its flaws, the Shuttle was unique. Previously, astronauts had launched to space in cramped capsules. Here was a roomy vehicle that could launch seven people and with them satellites and other equipment to use or release in orbit. Thanks to the Shuttle we were able to launch and service the Hubble Space Telescope, perform countless experiments in orbit, learn more about human spaceflight than ever before and build the International Space Station.

The Space Shuttle made spaceflight routine in an age where it had been anything but. It flew for the last time in July 2011 when Atlantis completed the STS-135 mission. And although it comes in for some deserved criticism, there's no doubt about its huge impact on space travel.

> "Thanks to the Space Shuttle we could build the ISS"

Three decades in orbit

How this pioneering spacecraft helped open up the final frontier

1981

First American female astronaut

Sally Ride became the first American woman to go into space on 18 June, 1983. She flew aboard Space Shuttle Challenger on the STS-7 mission, deploying communications satellites and conducting experiments during six days in orbit. Ride flew again in 1984 but sadly died from cancer in 2012.

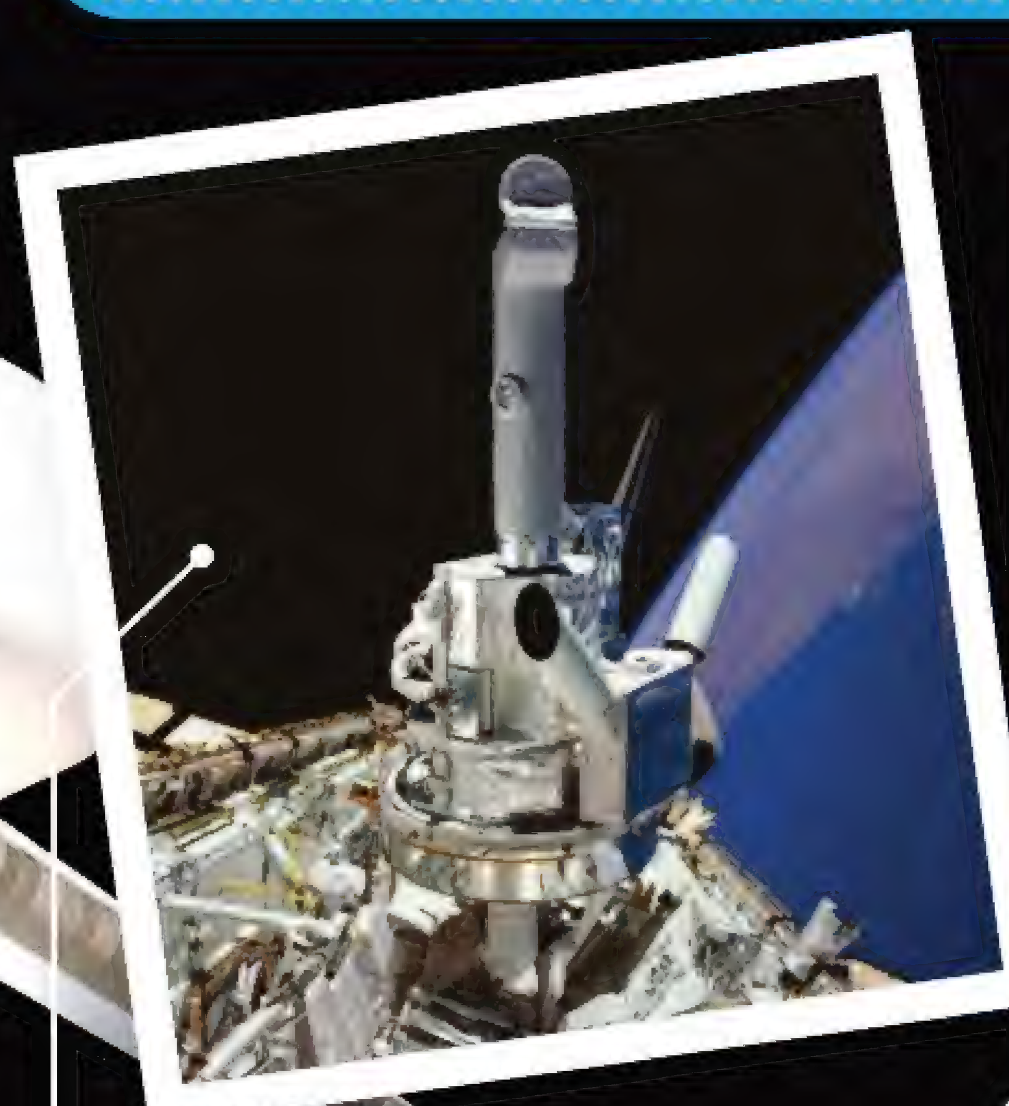
First African-American astronaut in space

Guion Bluford became the first African-American to go into space on Challenger's STS-8 mission on 5 September, 1983. This mission released an Indian communications and weather observation satellite. Bluford flew on three more Shuttle missions before leaving NASA in 1993.

1991

Launching Hubble

Arguably the most famous Shuttle mission, STS-31 on 24 April, 1990, saw the Hubble Space Telescope taken to orbit. It was deployed a day later in a high orbit 612 kilometres above Earth to prevent it being dragged into the atmosphere.



Longest mission

STS-80 was the longest Space Shuttle mission, totalling 17 days, 15 hours and 53 minutes. It was flown by Space Shuttle Columbia from 19 November to 7 December, 1996. The landing should have been two days earlier but bad weather prevented the Shuttle returning to the runway on schedule.

2001

Microgravity research

More than 20 Shuttle missions were dedicated to low-gravity research in a quest to understand the effects of microgravity on biological, chemical and physical systems. This was done aboard a specially designed Spacelab module, which was used to see how cells responded to flying in space, among other experiments.

Fixing Hubble

Four separate servicing missions between 1993 and 2009 kept Hubble working properly. The first replaced its primary mirror, which had been launched with a flaw. No other spacecraft before or after has been capable of such servicing missions.

"One of the greatest innovations, was that the entire Shuttle orbiter was designed to return to Earth"

Inside the Space Shuttle

How the design of this vehicle allowed it to perform groundbreaking science in orbit

The design of the Space Shuttle incorporated a number of key demands that needed to be met. These included making it highly reliable, able to carry a large variety of cargo and making it as versatile in orbit as possible. Most of these conditions were indeed met, making the large majority of Shuttle flights a success.

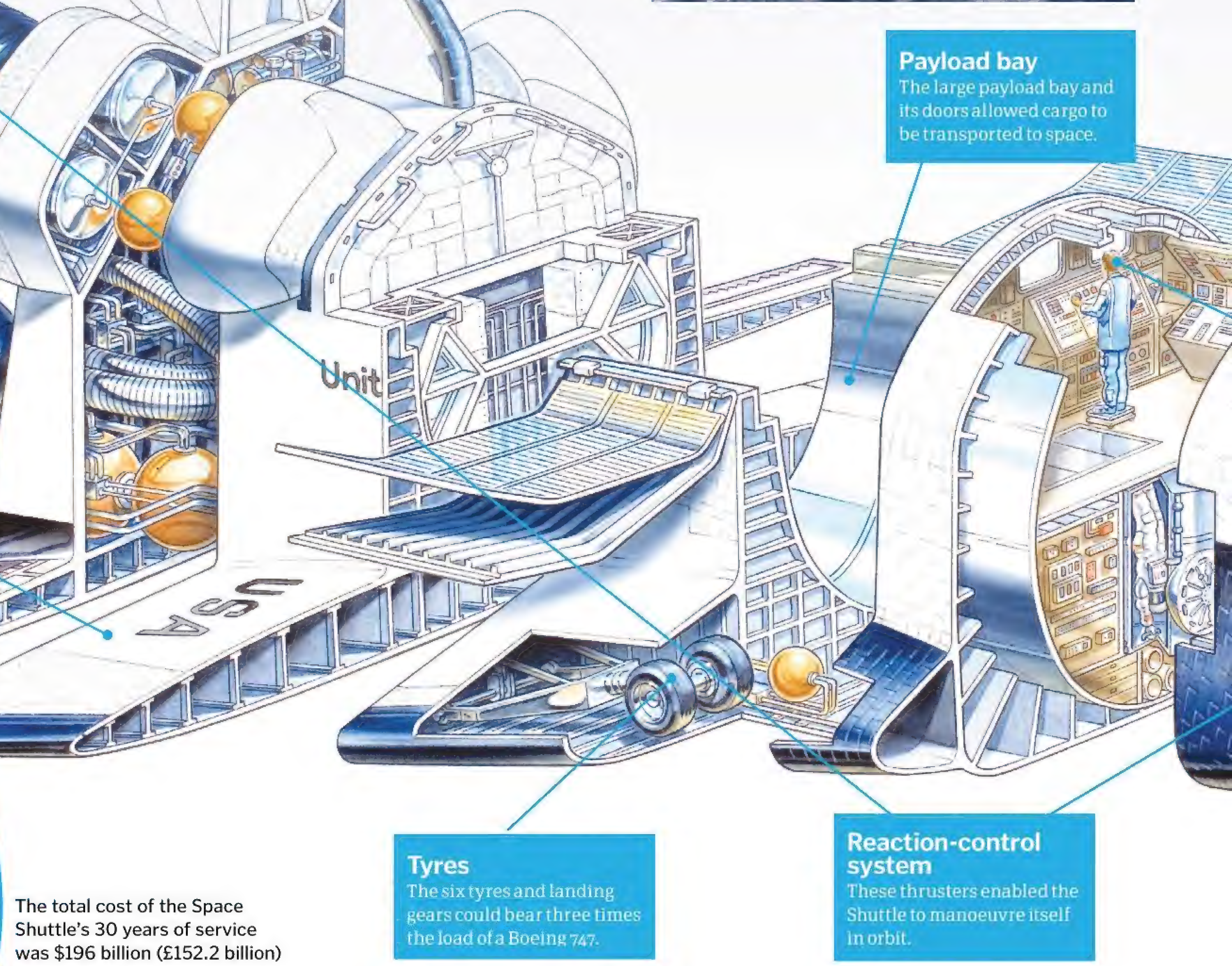
One of the Shuttle's key successes was its cargo bay. Using swinging bay doors it was able to accommodate lots of different payloads, from satellites to experiments. The doors were designed to not only be sturdy at the time of launch, but also to be opened when in space. Crucially, they had to close tightly for re-entry to prevent any hot gases getting inside the vehicle. A zipper-like system ensured the doors would close even if they were distorted by temperature changes or Earth's gravity.

Another key innovation was the use of the Canadarm, a long mechanical arm that was used to deploy satellites and other tasks. On later missions it was used to inspect the Shuttle for damage following the Columbia shuttle disaster, when a hole in the Shuttle's left wing caused it to disintegrate on re-entry in February 2003, tragically killing all seven crew members.

One of the greatest innovations, though, was that the entire Shuttle orbiter was designed to return to Earth as a glider. Because the main fuel tank was jettisoned on the way to orbit, the Shuttle did not have access to propellant during the descent even though its own engines were still attached. Using a low glide angle and a long drift time, the Shuttle was able to return from speeds in orbit of 27,800 kilometres per hour to about 400 kilometres per hour when landing.

Key components

The major parts of the Space Shuttle that made it a success

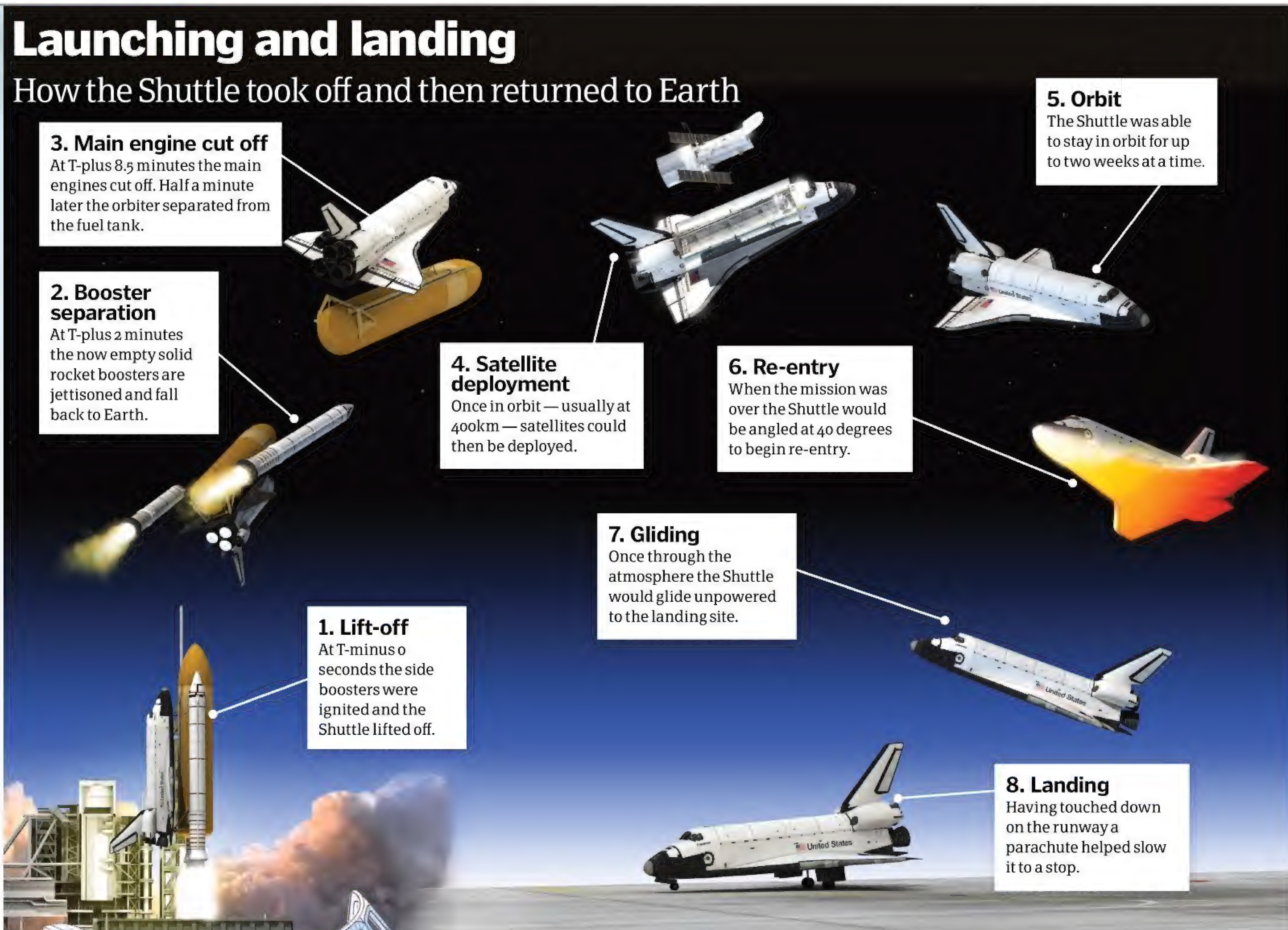


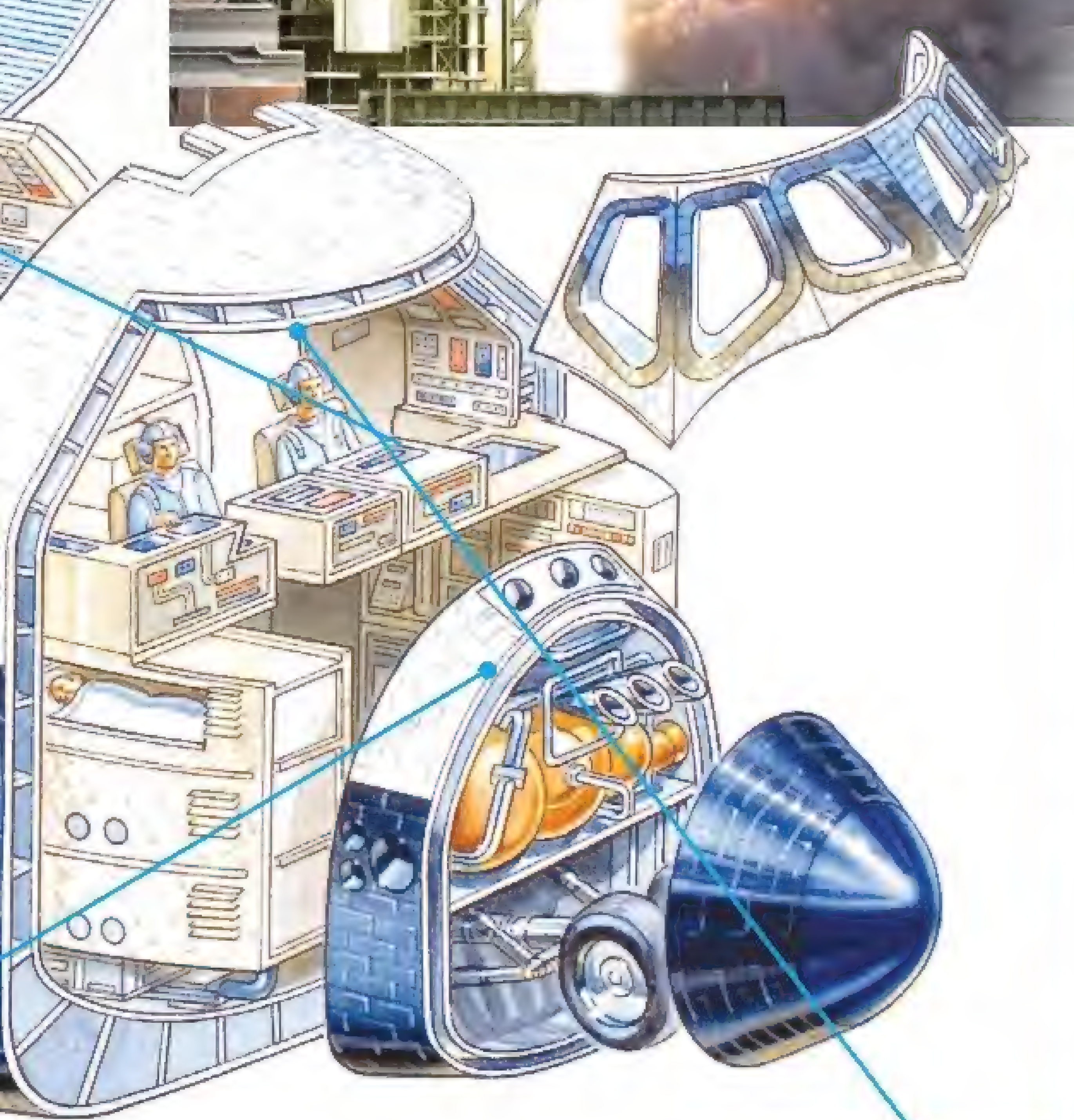
The total cost of the Space Shuttle's 30 years of service was $196 billion (£152.2 billion)

DID YOU KNOW? *It took two minutes and 30 seconds for the Space Shuttle to reach space, which is officially 100km in altitude*

Launching and landing

How the Shuttle took off and then returned to Earth



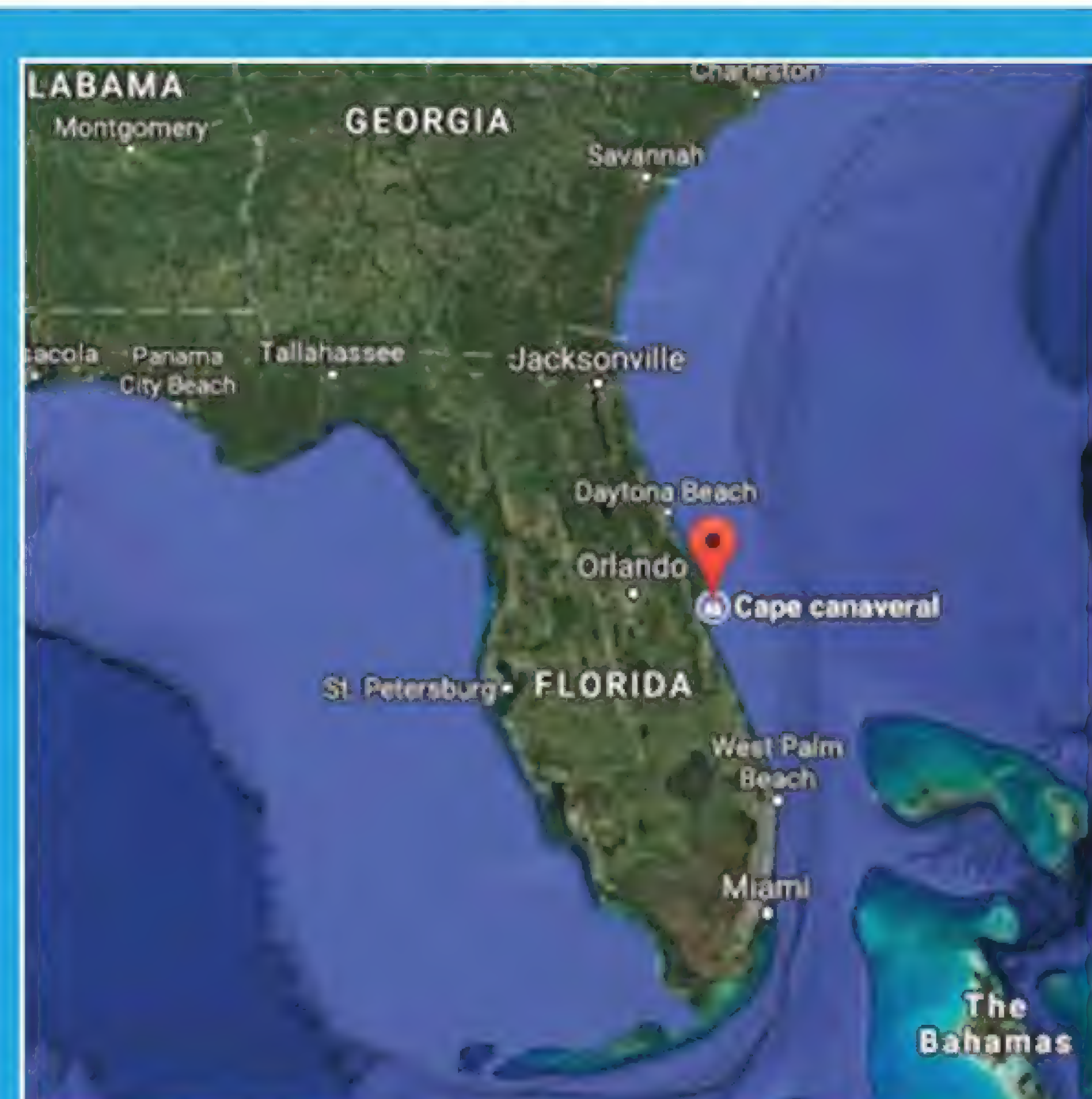


Crew cabin
The Space Shuttle cockpit and crew cabin housed up to seven people on each flight.

Why launch from Florida?

Cape Canaveral in Florida has a number of benefits for rocket launches. For one thing, it's relatively close to the equator, which gives rockets a speed boost from Earth's rotation. The rotation on our planet is fastest near the equator, so the closer you are — provided you launch in the same direction as Earth is rotating — the faster your rocket will go.

That's important for another reason. In order to get this speed boost you need to launch east in the Northern Hemisphere. As many rockets, including the Shuttle, have expendable parts, it's best if you launch over an ocean so that pieces do not fall on the ground. Thus, Florida is ideal as it's on the east coast and also relatively near the equator. Launch pads elsewhere in the world are located in similar positions for the same reasons.



Before moving to Cape Canaveral in July 1950, NASA launched its rockets from New Mexico

> "It was the first time solid rocket boosters [SRBs] were used on a manned vehicle"

Mission summary

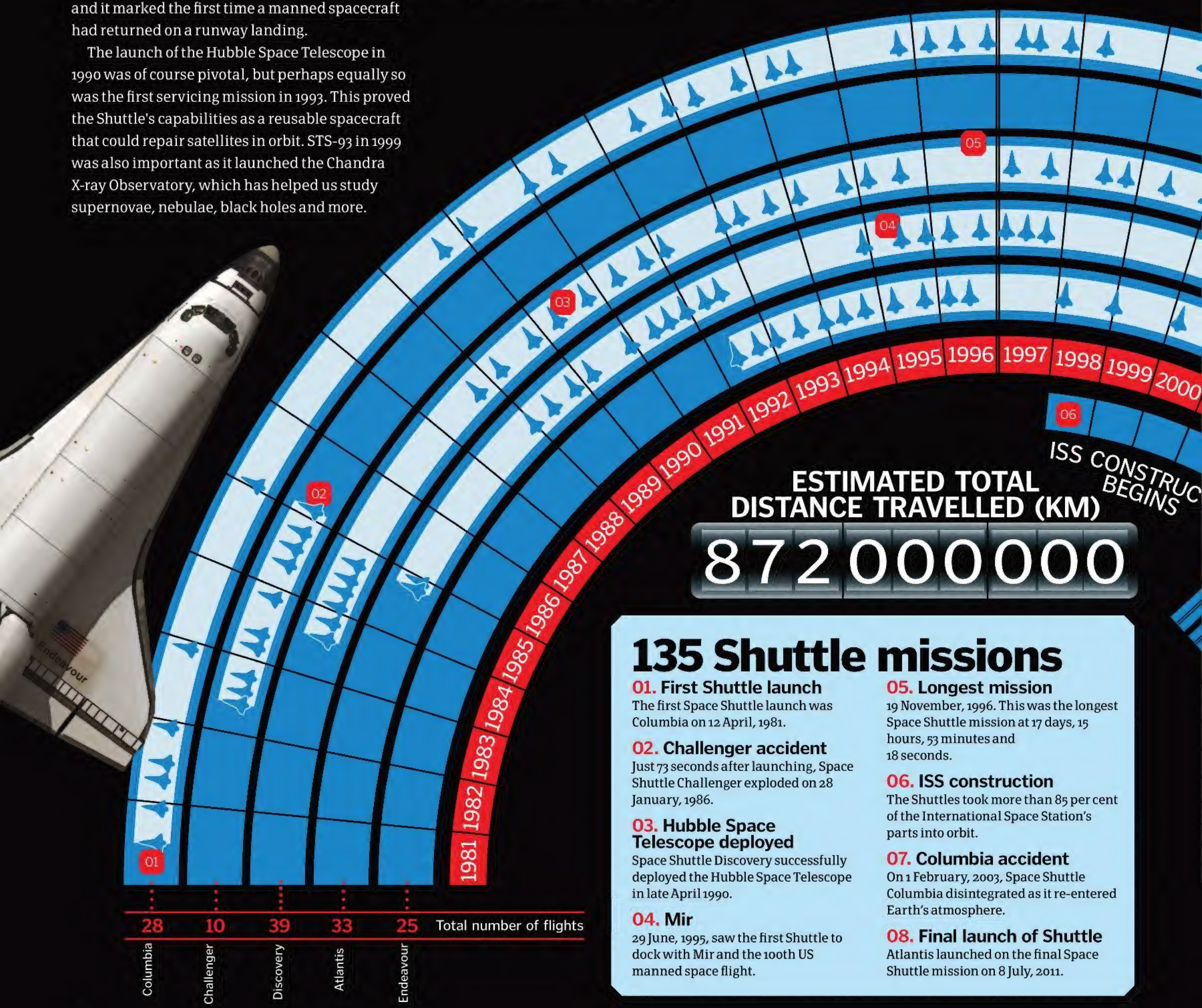
The trailblazing missions that made the Shuttle a legend

There were 135 Space Shuttle missions that successfully made it to orbit. All of these performed some incredible science. The inaugural launch of Space Shuttle Columbia on 12 April, 1981, was one of the most important, and it achieved a number of firsts. It was the first time solid rocket boosters (SRBs) were used on a manned vehicle, and it marked the first time a manned spacecraft had returned on a runway landing.

The launch of the Hubble Space Telescope in 1990 was of course pivotal, but perhaps equally so was the first servicing mission in 1993. This proved the Shuttle's capabilities as a reusable spacecraft that could repair satellites in orbit. STS-93 in 1999 was also important as it launched the Chandra X-ray Observatory, which has helped us study supernovae, nebulae, black holes and more.

Just prior to that in 1995, the STS-71 mission heralded a new era in partnership between the US and Russia when Space Shuttle Atlantis docked with the Mir space station. In 1998, Endeavour carried out the STS-88 mission that began the start of a new collaboration, the construction of the International Space Station (ISS).

The final mission, STS-135, launched on 8 July, 2011, was a sombre one as it brought the programme to a close. Atlantis delivered two major components to the ISS and brought to a close one of the greatest technological achievements of our time.



135 Shuttle missions

01. First Shuttle launch
The first Space Shuttle launch was Columbia on 12 April, 1981.

02. Challenger accident
Just 73 seconds after launching, Space Shuttle Challenger exploded on 28 January, 1986.

03. Hubble Space Telescope deployed
Space Shuttle Discovery successfully deployed the Hubble Space Telescope in late April 1990.

04. Mir
29 June, 1995, saw the first Shuttle to dock with Mir and the 100th US manned space flight.

05. Longest mission
19 November, 1996. This was the longest Space Shuttle mission at 17 days, 15 hours, 53 minutes and 18 seconds.

06. ISS construction
The Shuttles took more than 85 per cent of the International Space Station's parts into orbit.

07. Columbia accident
On 1 February, 2003, Space Shuttle Columbia disintegrated as it re-entered Earth's atmosphere.

08. Final launch of Shuttle
Atlantis launched on the final Space Shuttle mission on 8 July, 2011.

DID YOU KNOW? *The Space Shuttle orbiter fleet spent a combined 1,320 days in orbit during their 30 years of service*

Five key stats

238.5mn km

The distance covered by Space Shuttle Discovery, which travelled the furthest of all five Shuttles during its service.

100,000kg

The approximate weight of the Shuttle orbiter upon its re-entry into the Earth's atmosphere.

2mn kg

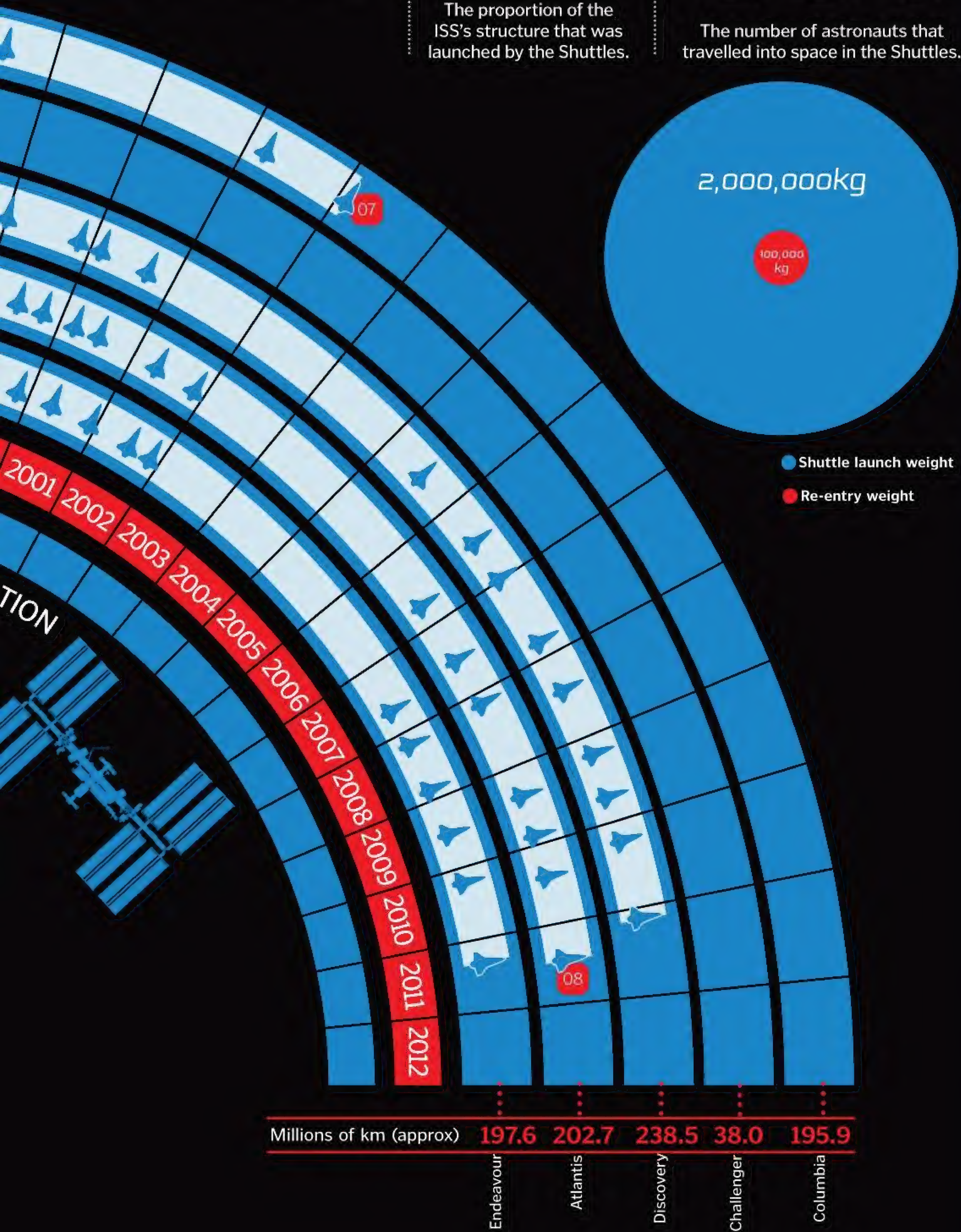
The combined weight of the Shuttle, boosters and tank at launch.

Over 85%

The proportion of the ISS's structure that was launched by the Shuttles.

600

The number of astronauts that travelled into space in the Shuttles.



The Shuttle's lasting legacy

While the Shuttle has now gone, it has left behind a shining legacy of exploration

International Space Station

The ISS is one of the greatest human-made constructions of all time. This vast $100 billion (£79.2 billion) station spans the size of a football pitch and has been continuously manned since 2000. It was assembled in space, and its construction arguably would not have been possible without the Space Shuttle. Today, astronauts continue to work on the ISS and conduct groundbreaking research not only into spaceflight but also into areas that improve our lives here on Earth.

Hubble Space Telescope

Since its launch in 1990, the Hubble Space Telescope has made countless discoveries. It has peered into the distant universe and found galaxies stretching back to just 400 million years after the Big Bang. It's taken Deep Field images of the cosmos, revealing a vast number of galaxies, and closer to home it has found water bursting from Jupiter's moon, Europa. Still going strong, who knows what the Hubble will find next?

Chandra X-ray Observatory

Still operational today, the Chandra X-ray Observatory is one of NASA's 'Great Observatories' along with Hubble, the Gamma Ray Observatory and the Spitzer Space Telescope. Launched on Columbia in 1999, it has observed the universe in X-rays to help astronomers see into the centre of a supernova. It has found a galaxy being eaten by another and also observed the X-ray emissions from the supermassive black hole at the centre of our galaxy.

Microgravity research

Thanks to the Shuttle we were able to perform microgravity research. It proved that cells could grow in microgravity, even with a lack of fluid mixing. Experiments also discovered that some immune cells were not as effective while in microgravity, which has implications for long-duration space travel. It also helped test the limits of how humans operate in space.

"The crew module will use parachutes and air bags to allow a cushioned touchdown"

The Orion spacecraft

How the replacement for NASA's Space Shuttle will take us to the moon and beyond


The first Orion missions will see it dock with the ISS to test its systems

The primary goals of the Orion spacecraft, which has been contracted to technology company Lockheed Martin by NASA, are to deliver crew and cargo to the International Space Shuttle and return astronauts to the moon after almost a 50-year wait. Orion made its first test flight in December 2014 and is scheduled to complete a lunar mission by the early 2020s.

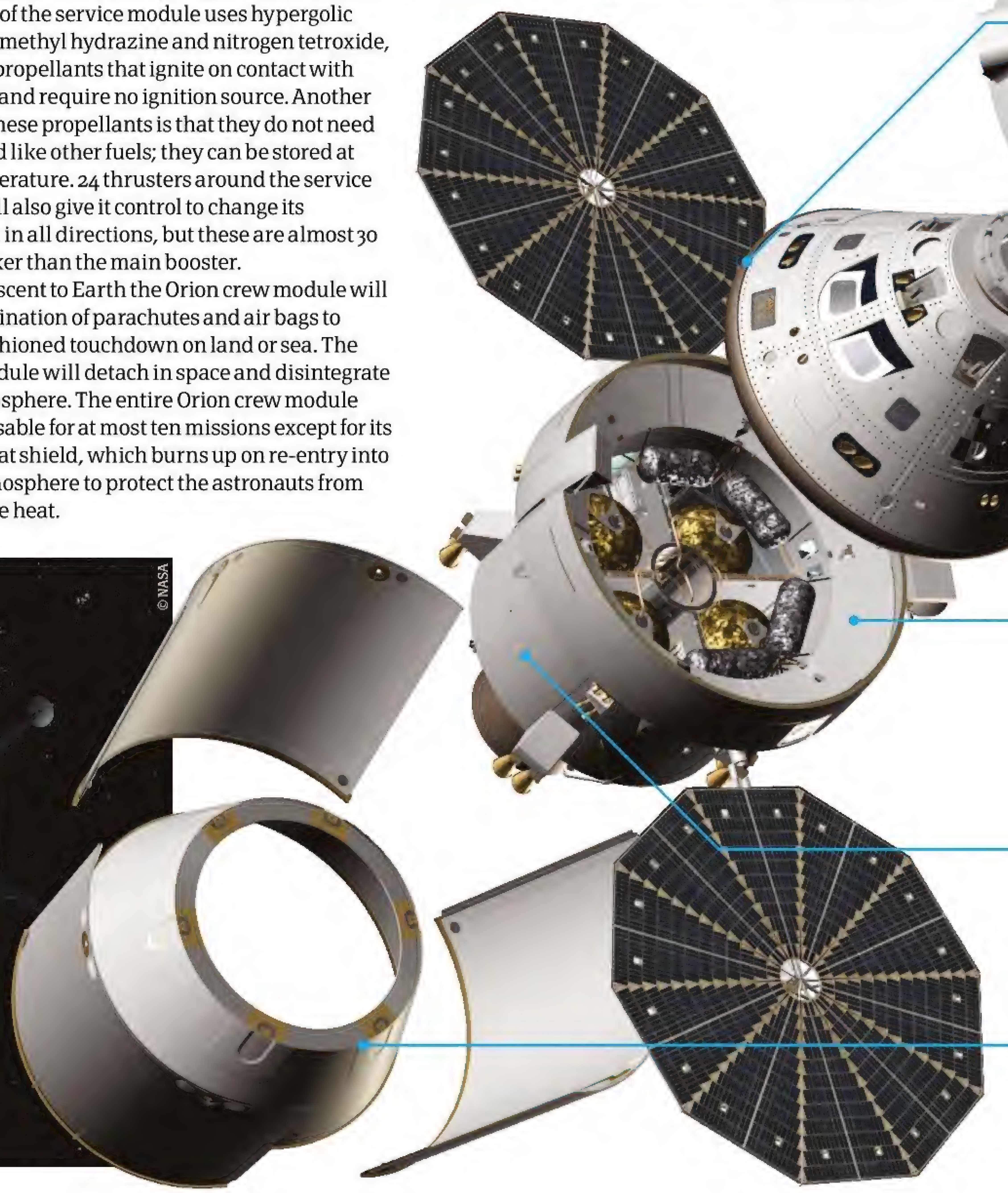
The Orion crew module is similar in design and appearance to the Apollo Command Module that first took astronauts to the moon. It is three times the volume of the Apollo module with the same 70° sloped top, deemed to be the safest and most reliable shape for re-entering Earth's atmosphere at high velocity. The Orion module has a diameter of five metres and a total mass of about 9,000kg including the cargo and the crew, which increases or decreases slightly for missions to the International Space Station and the moon respectively. Unlike the Apollo module, which had a crew capacity of three people, the Orion module can carry between four and six astronauts.

Attached to the crew module is the service module, responsible for propulsion, electrical power, communications and water/air storage. The service module is equipped with a pair of extendable solar panels that are deployed post-launch in addition to batteries to store power for times of darkness. Like the Orion crew module, the service module is also five metres in diameter to provide a clean fit between the two, and has a mass of about 3,700kg in addition to 8,300kg of propellant.

Exerting 33,000 newtons (7,500 pounds) of thrust, the engine of the service module uses hypergolic fuels monomethyl hydrazine and nitrogen tetroxide, which are propellants that ignite on contact with each other and require no ignition source. Another benefit of these propellants is that they do not need to be cooled like other fuels; they can be stored at room temperature. 24 thrusters around the service module will also give it control to change its orientation in all directions, but these are almost 30 times weaker than the main booster.

Upon descent to Earth the Orion crew module will use a combination of parachutes and air bags to allow a cushioned touchdown on land or sea. The service module will detach in space and disintegrate in the atmosphere. The entire Orion crew module will be reusable for at most ten missions except for its ablative heat shield, which burns up on re-entry into Earth's atmosphere to protect the astronauts from the extreme heat.


The Orion spacecraft will transport a lunar lander to the moon



5 TOP FACTS
JAXA PROJECTS

Orion
1 Although Orion is currently still on schedule, there are murmurs that the project could be canned in favour of using private companies for transporting crew to the ISS.

SpaceX Dragon
2 One of the competitors, the Dragon capsule transported crew members to the ISS in 2012, becoming the first private spacecraft to successfully dock there.

Boeing CST-100
3 After losing the Orion contract to Lockheed Martin, Boeing's capsule (similar in design to Orion) was helped by $18m of funding from NASA and could launch later this year.

Dream Chaser
4 Under development by the Sierra Nevada Corporation, this space plane won $20m from a NASA competition. It could land on almost any runway in the world.

X-37B
5 This US military space plane returned from a seven month orbit in 2010 and made the first ever spacecraft landing by autopilot, but its intentions are unknown.

DID YOU KNOW? An Orion test module used over 150,000 ping-pong balls to stop it sinking after splashing down in the ocean

© NASA

Launch abort
In a launch pad emergency, this rocket will lift the crew module and allow it to parachute safely to ground.

Heat shield
The ablative (burns on re-entry) heat shield protects the crew module as it returns to Earth alone before the parachutes deploy.

Airlock
The top of the crew module allows docking with other vehicles such as the ISS and lunar landers.

Crew module
Able to accommodate up to six crew members, this module provides a safe habitat for them to stay in during their journey.

Service module
This module supports the crew throughout their journey, providing life support and propulsion, before detaching upon Earth re-entry.

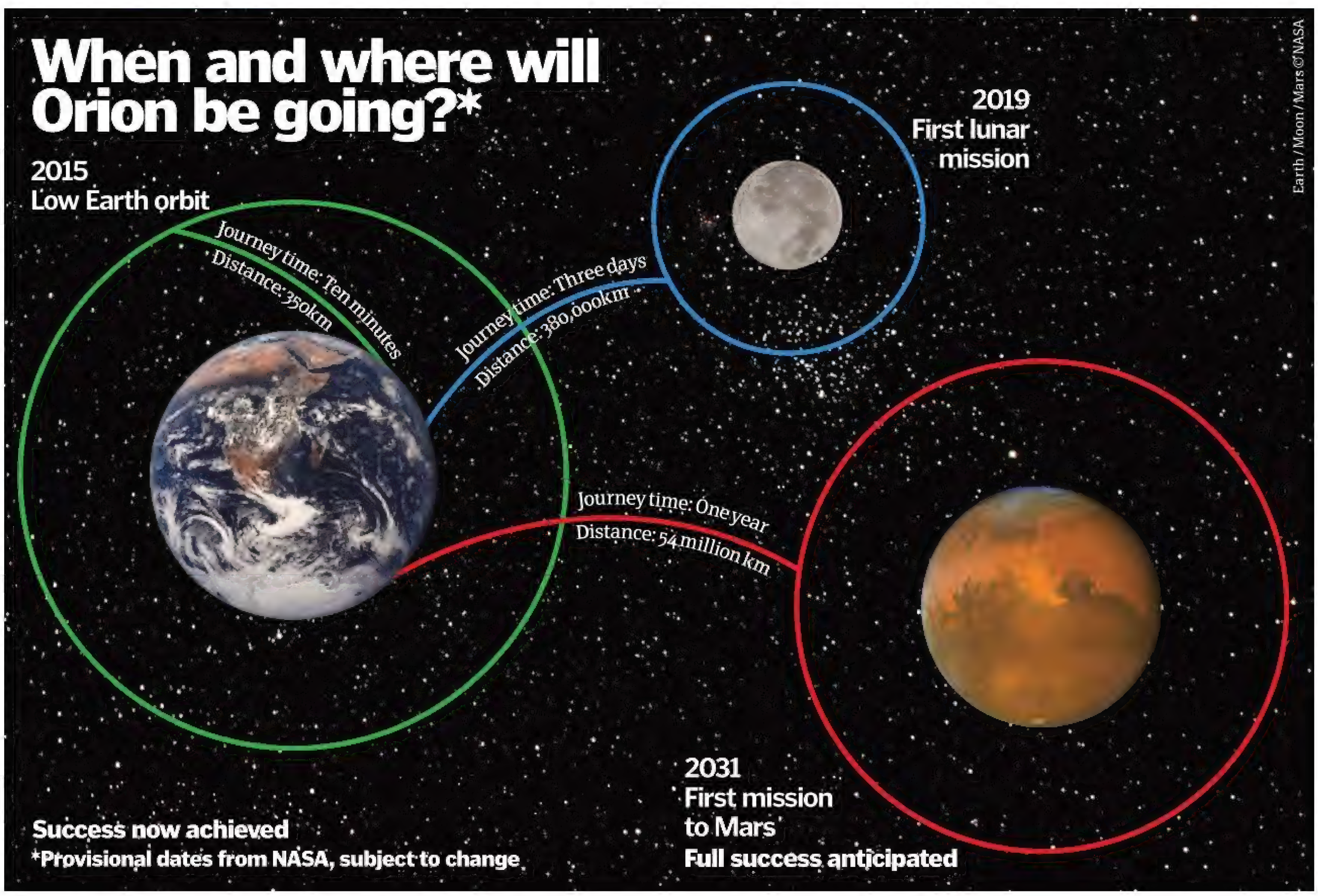
Cargo
Inside the service module, unpressurised cargo for the ISS and science equipment are stored.

Spacecraft adapter
Connects the Orion spacecraft to the launch rocket, and also protects components in the service module.

© NASA

The Launch Abort System will carry the crew module to safety in an emergency

When and where will Orion be going?*



*Provisional dates from NASA, subject to change

Earth / Moon / Mars © NASA

"When it is ready, VSS Unity should achieve altitudes of over 80 kilometres"

On board the SpaceShipTwo

Could this be the vehicle that will take you to space?

The first powered flight of VSS Enterprise shows the spaceplane in action

Virgin Galactic's reusable spaceplane, SpaceShipTwo, is designed to take two pilots and six passengers on the trip of a lifetime. Made by The Spaceship Company, part of Virgin Galactic, this vessel will be carried high into the atmosphere by the jet-powered aircraft WhiteKnightTwo, before engaging its rocket engines for a brief trip out of this world.

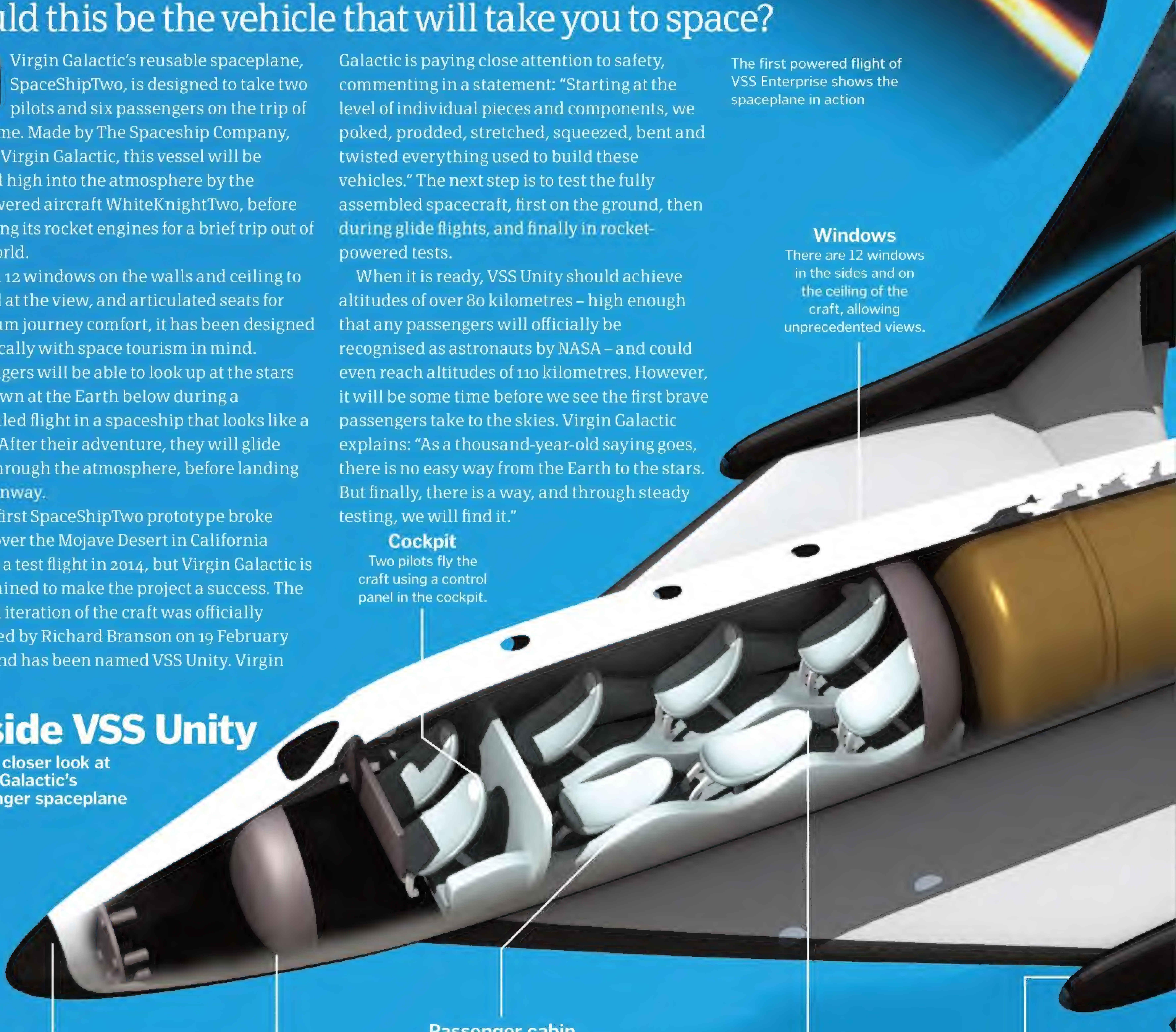
With 12 windows on the walls and ceiling to marvel at the view, and articulated seats for optimum journey comfort, it has been designed specifically with space tourism in mind. Passengers will be able to look up at the stars and down at the Earth below during a controlled flight in a spaceship that looks like a plane. After their adventure, they will glide back through the atmosphere, before landing on a runway.

The first SpaceShipTwo prototype broke apart over the Mojave Desert in California during a test flight in 2014, but Virgin Galactic is determined to make the project a success. The second iteration of the craft was officially unveiled by Richard Branson on 19 February 2016, and has been named VSS Unity. Virgin Galactic is paying close attention to safety, commenting in a statement: "Starting at the level of individual pieces and components, we poked, prodded, stretched, squeezed, bent and twisted everything used to build these vehicles." The next step is to test the fully assembled spacecraft, first on the ground, then during glide flights, and finally in rocket-powered tests.

When it is ready, VSS Unity should achieve altitudes of over 80 kilometres – high enough that any passengers will officially be recognised as astronauts by NASA – and could even reach altitudes of 110 kilometres. However, it will be some time before we see the first brave passengers take to the skies. Virgin Galactic explains: "As a thousand-year-old saying goes, there is no easy way from the Earth to the stars. But finally, there is a way, and through steady testing, we will find it."

Inside VSS Unity

Take a closer look at Virgin Galactic's passenger spaceplane



Windows
There are 12 windows in the sides and on the ceiling of the craft, allowing unprecedented views.

Cockpit
Two pilots fly the craft using a control panel in the cockpit.

Thrusters
Positioned at the front of the spaceplane and on the wings, thrusters provide additional control during flight.

Fuselage
The body and nose of the plane are constructed from carbon fibre.

Passenger cabin
SpaceShipTwo has been designed with the passenger's experience in mind, aiming to minimise the discomfort of G-forces.

Articulated seats
The passenger seats are upright during ascent, and reclined during re-entry.

Thrusters

VSS Enterprise crash

After 55 successful test flights, the first SpaceShipTwo, VSS Enterprise, broke apart over the Mojave Desert in California, killing co-pilot Michael Alsbury. SpaceShipTwo is equipped with a 'feathering system', designed to rotate the tail and wings for a smooth descent through Earth's atmosphere, but Alsbury unlocked it too early. With the rocket engine still firing, and with VSS Enterprise travelling at a little under the speed of sound, the feather system deployed, pulling the spaceplane apart. The other co-pilot, Peter Siebold, managed to parachute to safety. However, the computer system should have prevented the disaster, and it has been changed for the new SpaceShipTwo. This time, it will not be possible for the crew to unlock the feather system too soon.

The National Transportation Safety Board examines the remains of VSS Enterprise

Fuel
The VSS Unity will use a rubber-based, solid fuel, making combustion more efficient.

Feathered configuration
The wings move upwards during re-entry, slowing descent.

Standard configuration
SpaceShipTwo can adopt two different configurations, behaving like a winged plane or a capsule.

Nitrous oxide tank
The hybrid solid and liquid fuel engine can be shut down during the flight.

"We poked, prodded, stretched, squeezed, bent and twisted everything"

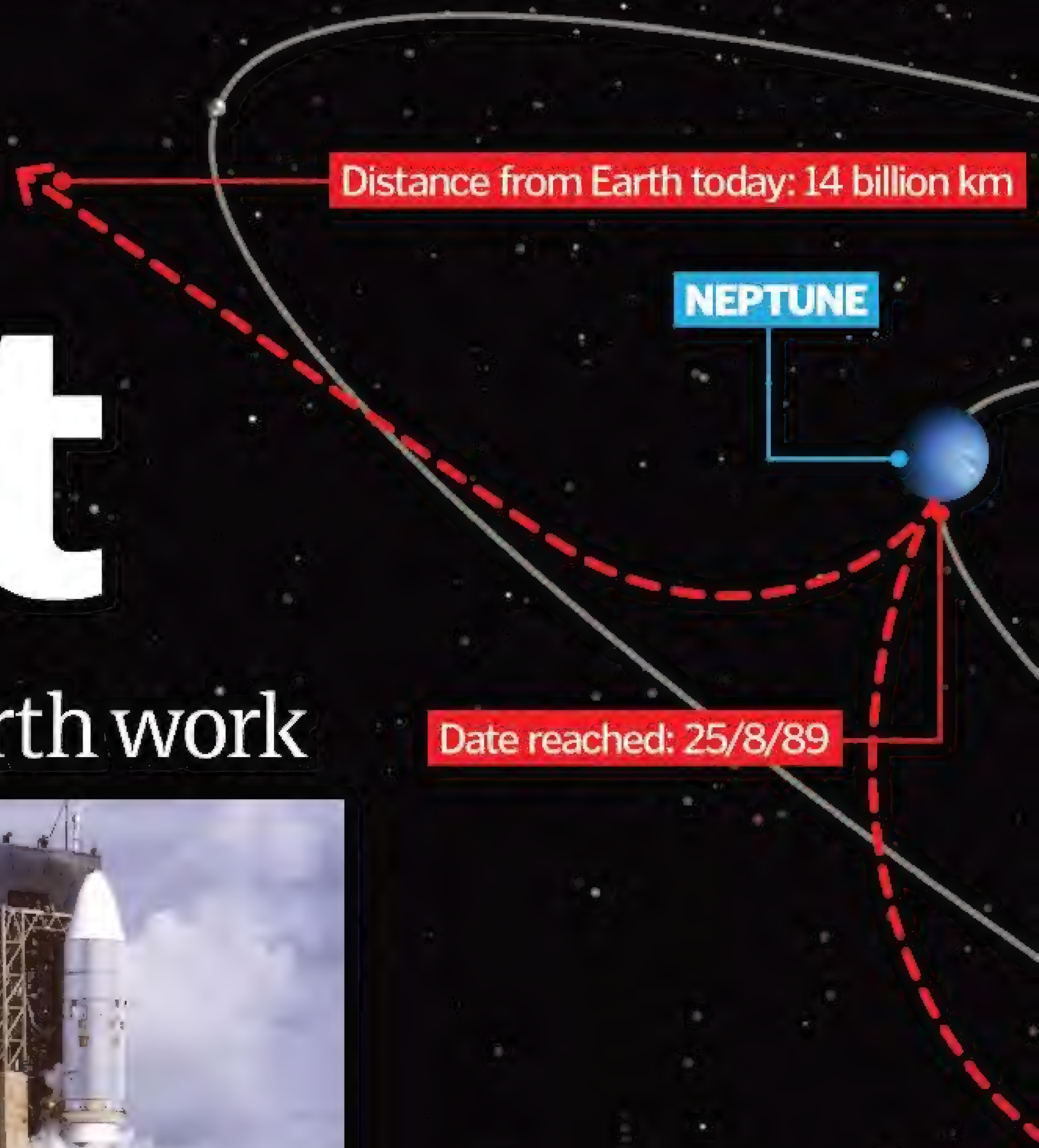
Virgin Galactic hopes to take tourists on short trips to space

Flying high

See how SpaceShipTwo compares to other high fliers

"The probes have studied all the major planets of the solar system past Mars"

Voyager spacecraft



How the furthest man-made objects from Earth work

On 20 August 1977 Voyager 2 launched from Cape Canaveral in Florida aboard a Titan-Centaur rocket, heralding the start of one of the most ambitious deep space exploration missions of all time. Two weeks later Voyager 1 was sent up in an identical launch, although its greater speed meant that it eventually overtook Voyager 2. The list of accomplishments by the two probes is astounding. Between them they have studied all of the major planets of the solar system past Mars, in addition to some moons of Jupiter and Saturn, making countless new discoveries in the process. Now, as the furthest man-made objects from Earth, they are on their way out of the solar system.

The launch of the mission coincided with a favourable alignment of the planets in the Seventies that would allow Voyager 2 to visit Jupiter, Saturn, Uranus and Neptune. The list of achievements by the two Voyager spacecraft is extensive. The Voyager mission was only the second – after Pioneer 10 and 11 in 1974 and 1975, respectively – to visit Jupiter and then Saturn, but it also discovered the existence of rings around Jupiter, while Voyager 2 was the first mission to visit Uranus and Neptune.

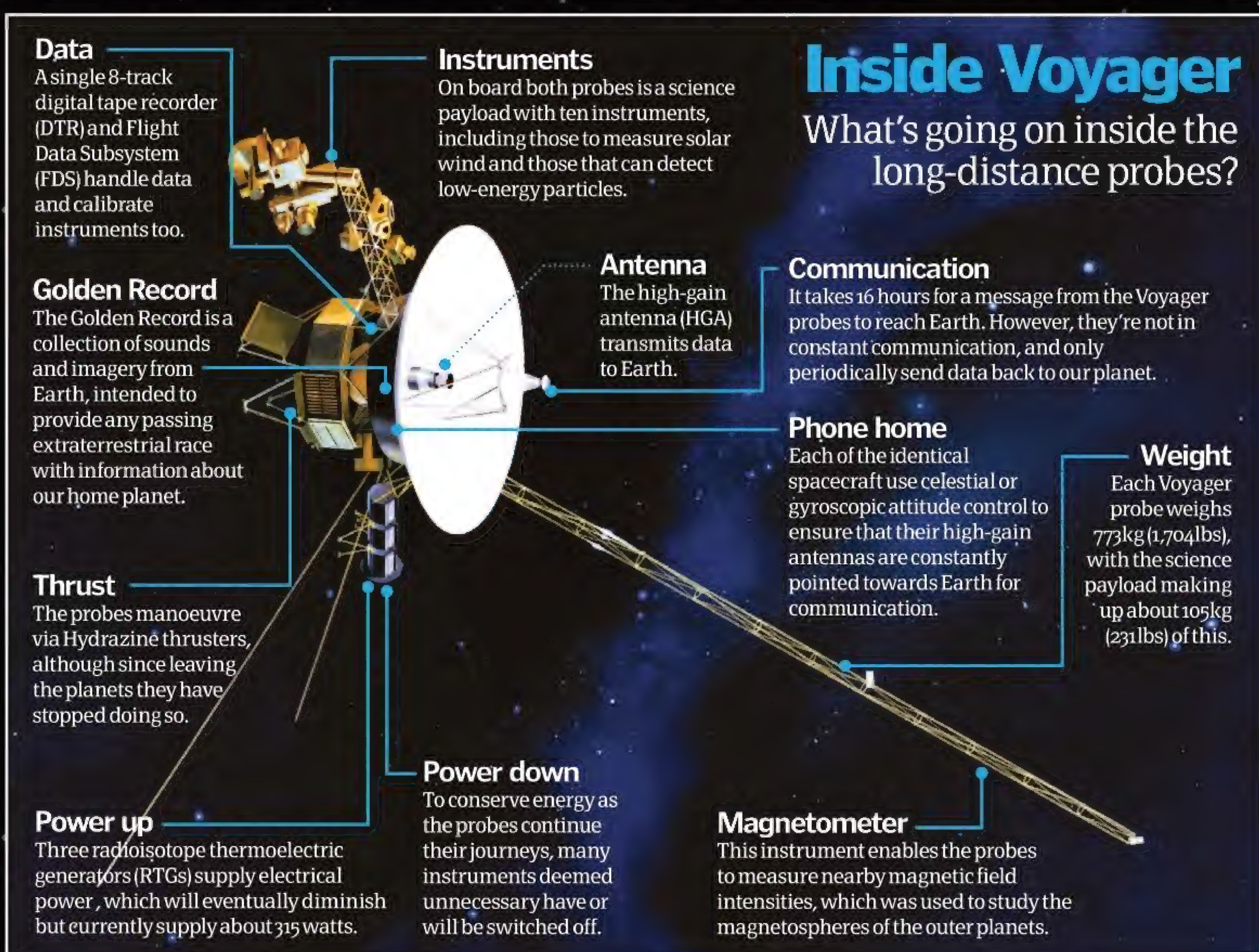
The primary objective of the mission was to study Jupiter and Saturn, but once it became apparent that the spacecraft could continue working, the mission was extended to include Neptune and Uranus for Voyager 2. Voyager 1 could have travelled to Pluto, but NASA decided to extend its mission to Saturn and its moon Titan, leaving the dwarf planet Pluto one of the largest bodies in the solar system yet to be explored.

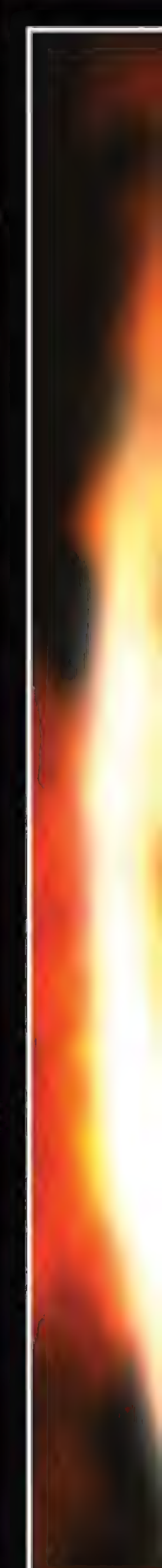
The Voyager probes obtain power from their radioactive generators, which have kept them running even at such a great distance from Earth and will continue to do so until about 2020, when they will no longer be able to power their instruments. Voyager 1 is roughly now over 17 billion kilometres (10.6 billion miles) from the Sun, while Voyager 2 is at a distance of over 14 billion kilometres (8.5 billion miles).

After making so many groundbreaking discoveries, both spacecraft are now on their way out of the solar system. They are both expected to pass out of the Sun's influence and into interstellar space in the coming years, although it is not entirely clear when this will happen as no machine has yet experienced the conditions that the Voyager probes are about to endure.

In 40,000 years, Voyager 1 should be within 1.6 light years (9.4 trillion miles) of a star in the constellation of Camelopardalis thought to harbour a planetary system. 256,000 years later, Voyager 2 will be 4.3 light years (25 trillion miles) from Sirius, which is the brightest star other than the Sun in our night sky.


Voyager 2 launched atop a Titan III-Centaur rocket on 20 August 1977





5 TOP FACTS
VOYAGER DISCOVERIES

Moons
1 Around the outer planets the Voyager probes discovered 23 new moons, including five around Saturn and 11 around Uranus, in addition to imaging our own.

Interstellar medium
2 Both of the Voyager probes are now in a region where the Sun's influence is increasingly waning, and soon they will enter the interstellar medium.

Atmospheres
3 Voyager probes 1 and 2 both provided unprecedented information about the atmospheres of the following planets: Jupiter, Saturn, Uranus and Neptune.

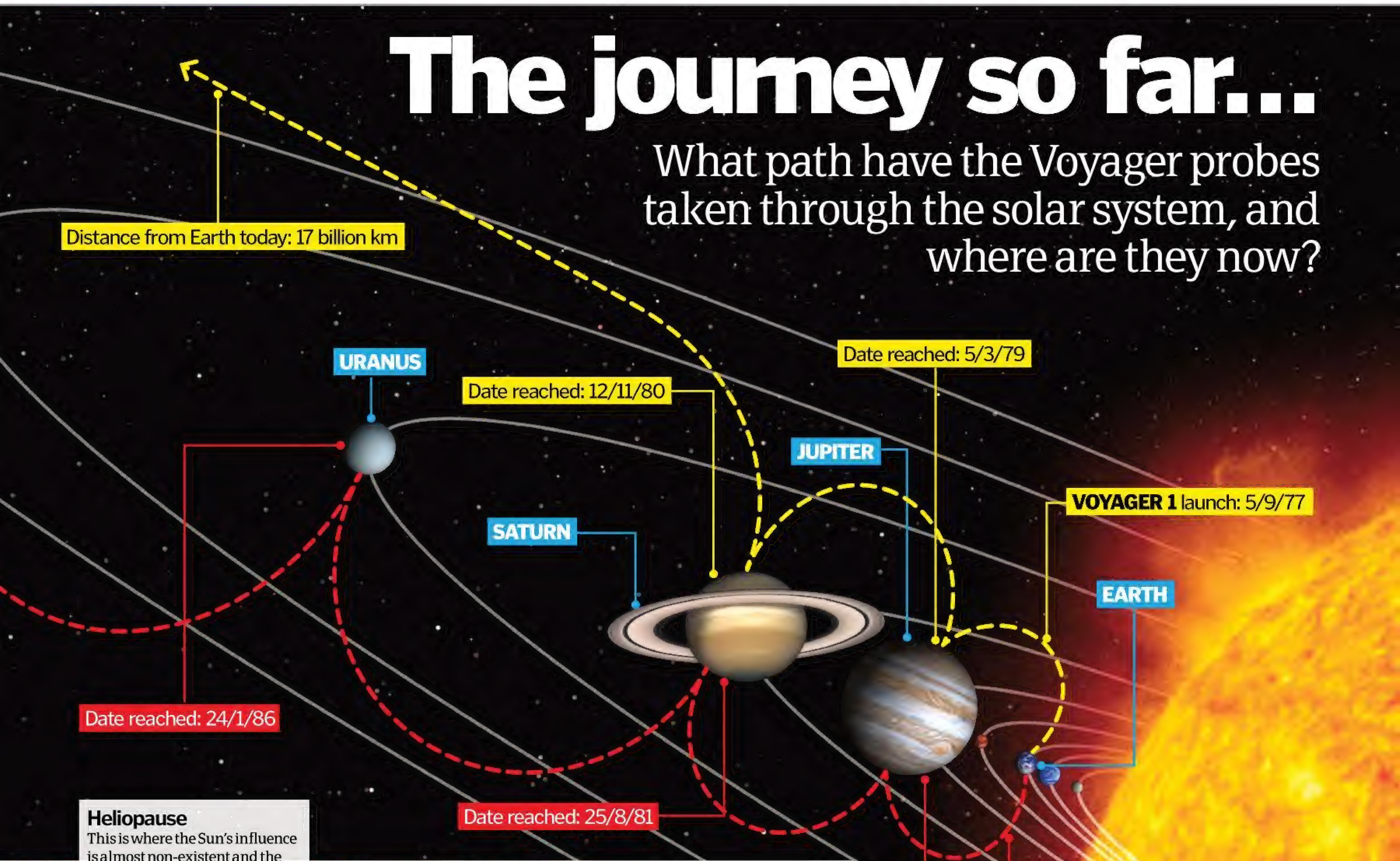
Jupiter
4 The probes discovered for the first time a ring system encircling Jupiter, and they also observed hurricane-like storms in the planet's atmosphere.

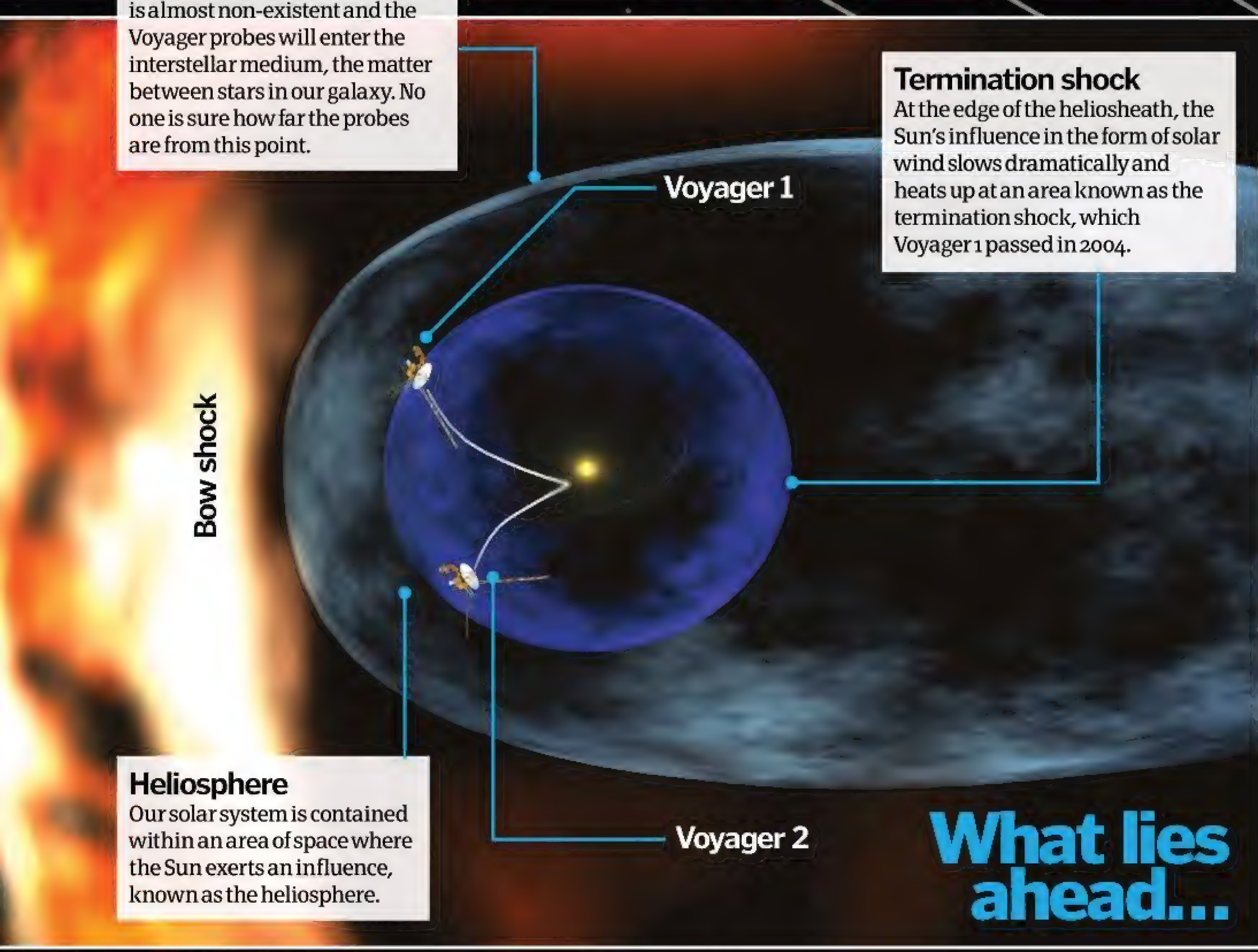
Io
5 Voyager 1 discovered the only known body in the solar system other than Earth to be volcanically active: Jupiter's moon Io. This moon also affects the surrounding Jovian system.

DID YOU KNOW? Voyager 1 is now travelling at 38,000mph, while Voyager 2 is slightly slower at 35,000mph

The journey so far…

What path have the Voyager probes taken through the solar system, and where are they now?



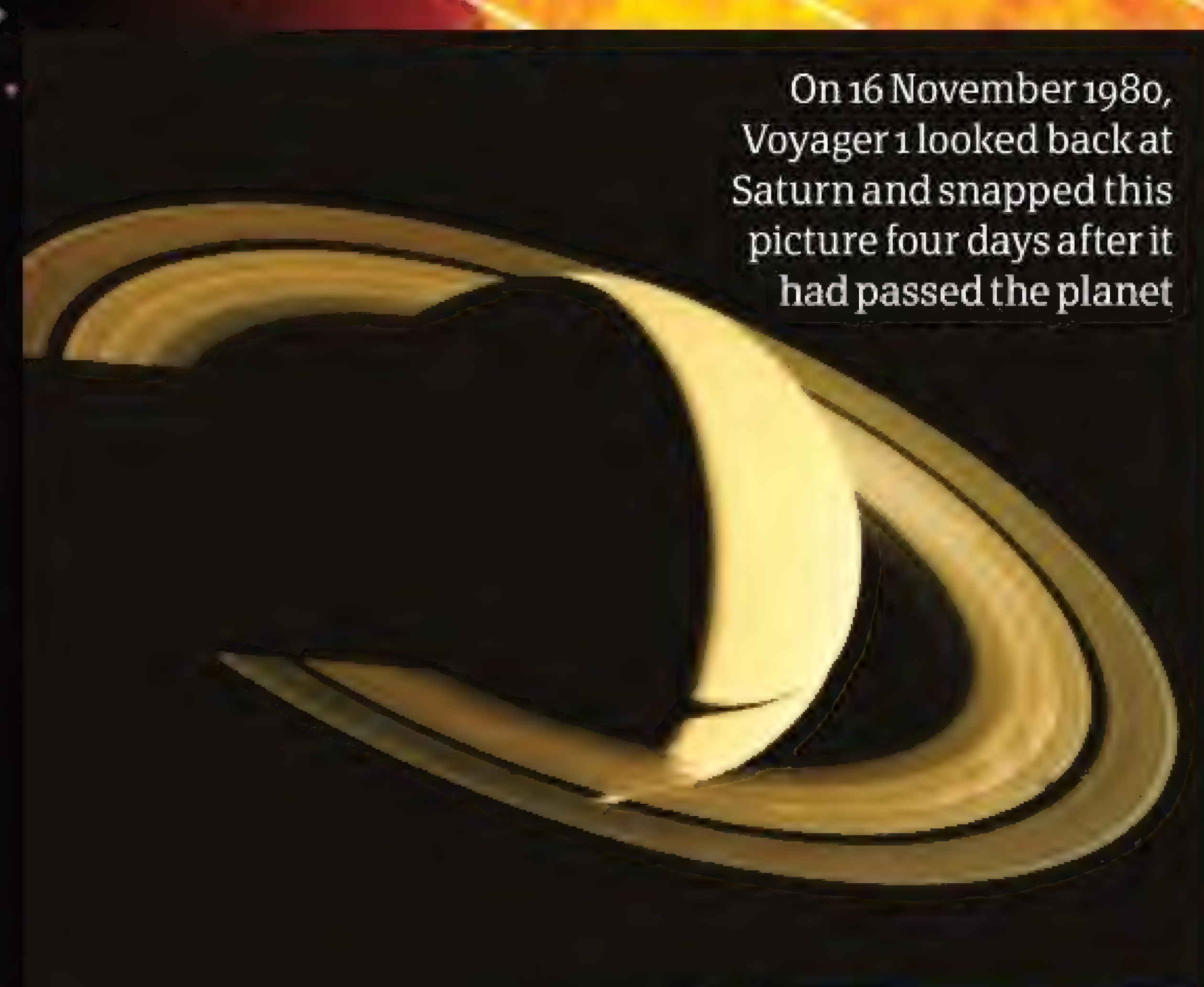


Heliopause
This is where the Sun's influence is almost non-existent and the Voyager probes will enter the interstellar medium, the matter between stars in our galaxy. No one is sure how far the probes are from this point.

Termination shock
At the edge of the heliosheath, the Sun's influence in the form of solar wind slows dramatically and heats up at an area known as the termination shock, which Voyager 1 passed in 2004.

Heliosphere
Our solar system is contained within an area of space where the Sun exerts an influence, known as the heliosphere.

What lies ahead…



On 16 November 1980, Voyager 1 looked back at Saturn and snapped this picture four days after it had passed the planet

"In the case of human payloads, these were delivered via an airlock located at the front of the shuttle"

Space Shuttle payload bay

How did this colossus deliver tons of supplies and technology into space?

NASA's Space Shuttle launch vehicles undertook over 130 missions during their lifetime, carrying hundreds of tons of technology into space. It had a refined system for delivering payloads to the intended target – be that simply low-Earth orbit or space stations such as the ISS – following a five-step mission profile.

After liftoff, solid-rocket booster separation, external fuel tank separation and orbital insertion, the in-orbit operations could begin. In the case of human payloads, these were delivered via an airlock located at the front of the shuttle, but when dealing with inanimate cargo, that required accessing the internal storage hold, known as the payload bay. Tech and supplies were accessed by the opening of the shuttle's payload bay doors, which swung open from the top of the spacecraft.

Once the bay doors were open, the resources within could be collected either by an EVA (extravehicular activity, or spacewalk), or using a robotic mechanical arm called Canadarm. This arm, 15.2 metres (50 feet) long and 38 centimetres (15 inches) in diameter, had six degrees of freedom and was specially built to manoeuvre cargo from the bay to their final position on the ISS. Once the payload for a mission had been successfully delivered, the Space Shuttle would then be prepared for re-entry and the return trip to Earth.

The STS-133 payload canister is lifted into the rotating service structure on Launch Pad 39A

The Canadarm being used to retrieve cargo from within the Space Shuttle

22,753kg

BIGGEST PAYLOAD TO SPACE

The heaviest non-commercial payload ever launched – the Chandra X-ray Observatory – weighed in at 22,753 kilograms (50,161 pounds) on Space Shuttle mission STS-93 in 1999.

DID YOU KNOW? The last Space Shuttle launch – STS-135 – carried a payload of 3,630kg (8,000lb) of supplies

Endeavour in flight clearly showing its spacious payload bay on STS-111

Automated transfer vehicles

How do these European resupply craft keep the ISS fully stocked?


Each ATV is capable of carrying 6.6 tons of cargo to the ISS

The European Space Agency's automated transfer vehicles (ATVs) are unmanned spacecraft designed to take cargo and supplies to the International Space Station (ISS), before detaching and burning up in Earth's atmosphere. They are imperative in maintaining a human presence on the ISS, bringing various life essentials to the crew suchas water, food and oxygen, in addition to new equipment and tools for conducting experiments and general maintenance of the station.

The first ATV to fly was the Jules Verne ATV-1 in 2008; it was named after the famous 19th-century French author who wrote *Around The World In 80 Days*. This was followed by the (astronomer) Johannes Kepler ATV-2 in February 2011, and will be succeeded by the (physicists) Edoardo Amaldi and Albert Einstein ATVs in 2012 and 2013, respectively.

The ATV-1 mission differed somewhat from the subsequent ones as it was the first of its kind attempted by the ESA and thus various additional procedures were carried out, such as testing the vehicle's ability to manoeuvre in close proximity to the ISS for several days to prevent it damaging the station when docking. However, for the most part, all ATV missions are and will be the same.

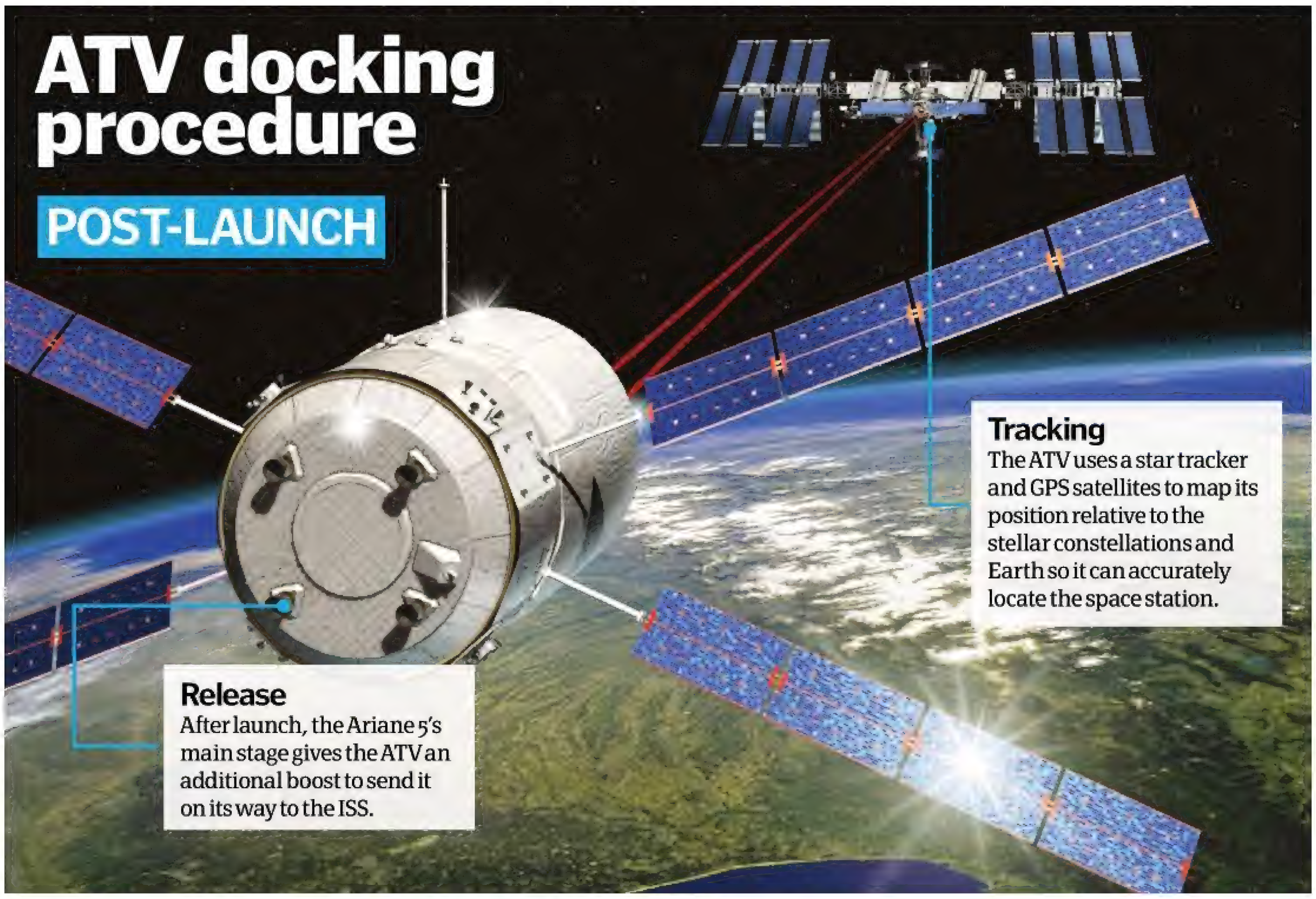
ATVs are launched into space atop the ESA's Ariane 5 heavy-lift rocket. Just over an hour after launch the rocket points the ATV in the direction of the ISS and gives it a boost to send it on its way, with journey time to the station after separation from the rocket taking about ten days. The ATV is multifunctional, meaning that it is a fully automatic vehicle that also possesses the necessary human safety requirements to be boarded by astronauts when attached to the ISS. Approximately 60 per cent of the entire volume of the ATV is made up of the integrated cargo carrier (ICC). This attaches to the service module, which propels and manoeuvres the vehicle. The ICC can transport 6.6 tons of dry and fluid cargo to the ISS, the former being pieces of equipment and personal effects and the latter being refuelling propellant and water for the station.

As well as taking supplies, ATVs also push the ISS into a higher orbit, as over time it is pulled towards Earth by atmospheric drag. To raise the ISS, an ATV uses about four tons of its own fuel over 10-45 days to slowly nudge the station higher.

The final role of an ATV is to act as a waste-disposal unit. When all the useful cargo has been taken off the vehicle, it is filled with superfluous matter from the ISS until no more can be squeezed in. At this point the ATV undocks from the station and is sent to burn up in the atmosphere.

ATV docking procedure

POST-LAUNCH



Tracking
The ATV uses a star tracker and GPS satellites to map its position relative to the stellar constellations and Earth so it can accurately locate the space station.

Release
After launch, the Ariane 5's main stage gives the ATV an additional boost to send it on its way to the ISS.

APPROACH

Locking on
When it's 300m (984ft) from the ISS, the ATV switches to a high-precision rendezvous sensor called the video meter to bring it in to dock.

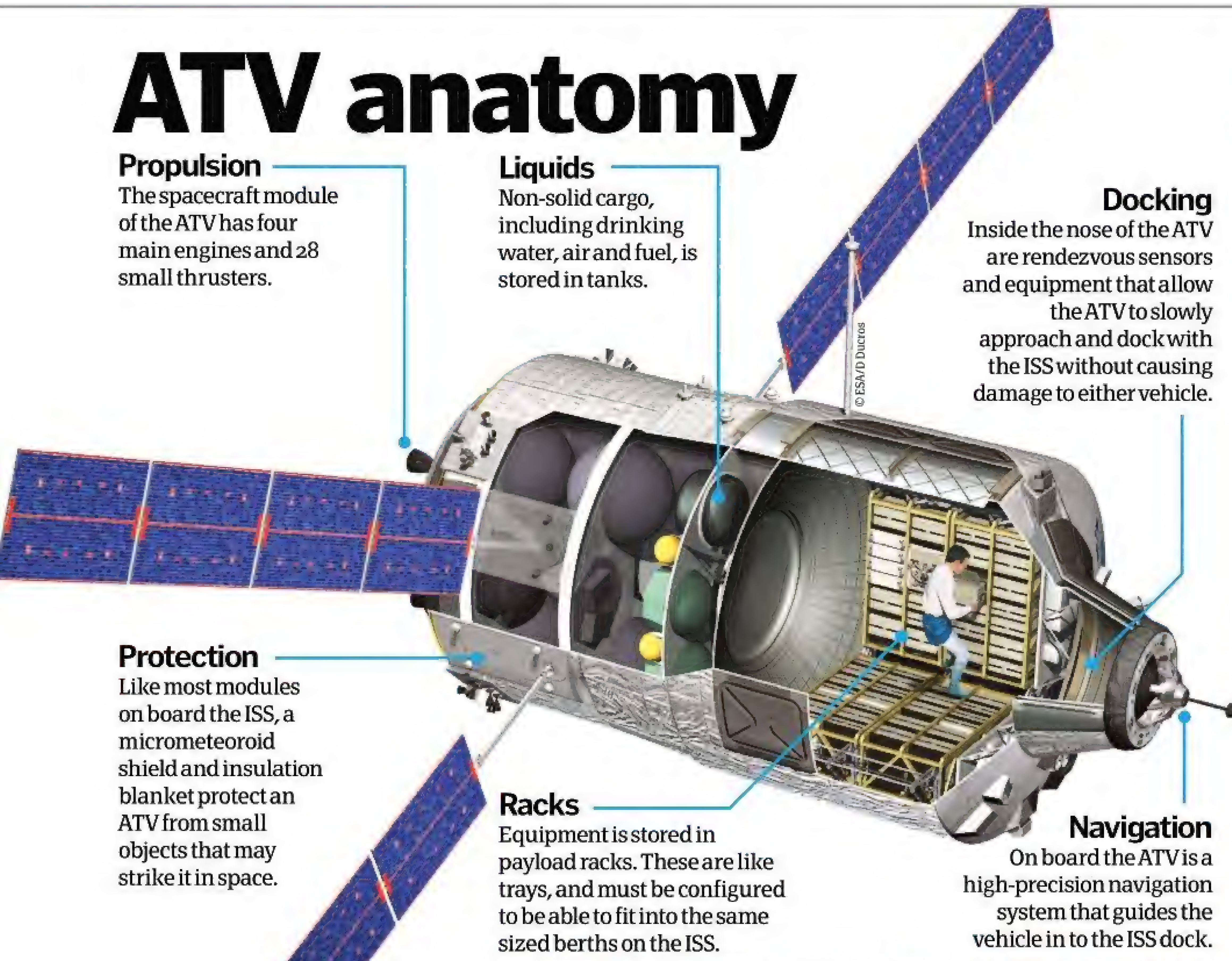
THE STATS HOW AN ATV MEASURES UP

LENGTH 10.7m (35.1ft) DIAMETER **4.5m (14.8ft)** SPAN 22.3m (73.2ft)

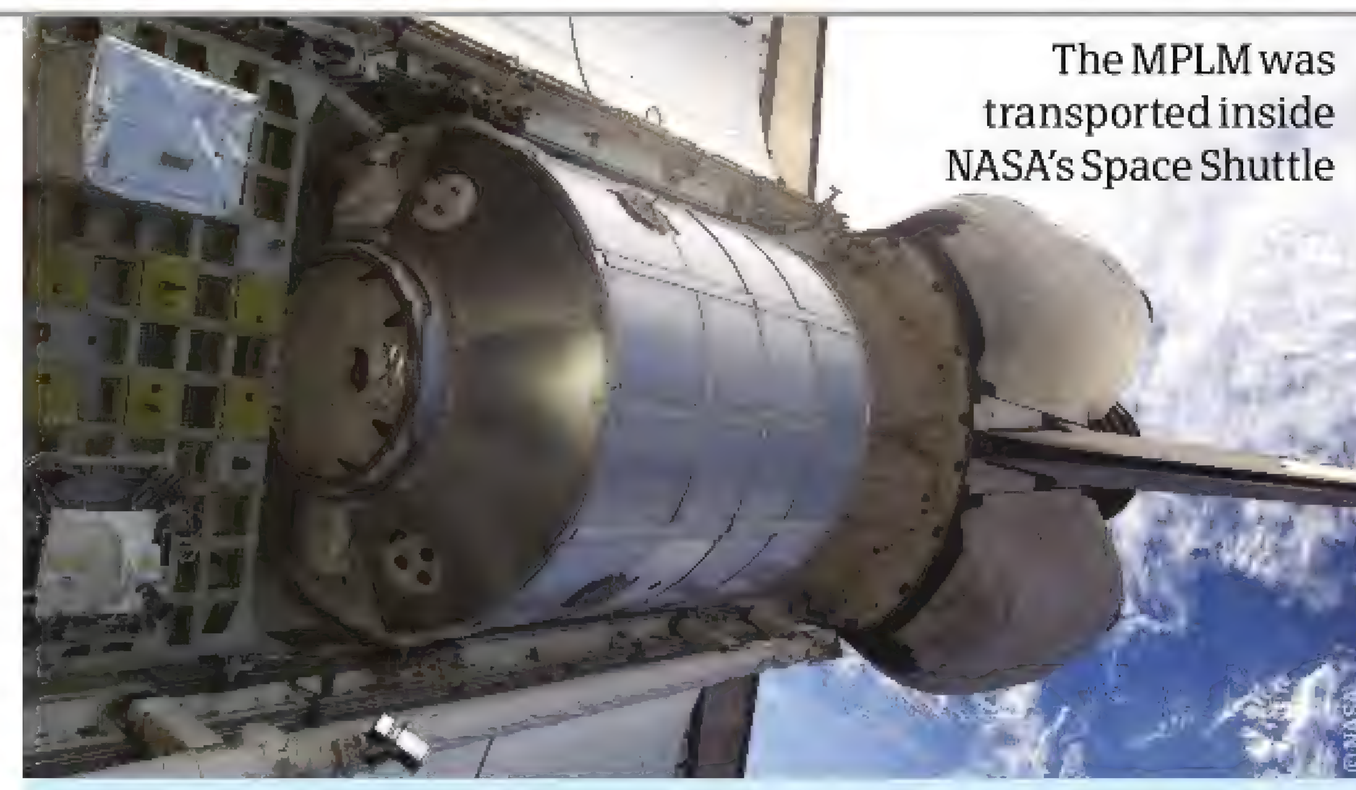
VOLUME **48m³ (1,695ft³)** LAUNCH MASS 20,700kg (45,636lb)

DID YOU KNOW? The ESA hopes to upgrade the ATV into a human-carrying vehicle by 2020

ATV anatomy



Currently, ESA ground control pilots the ATVs remotely



The MPLM was transported inside NASA's Space Shuttle

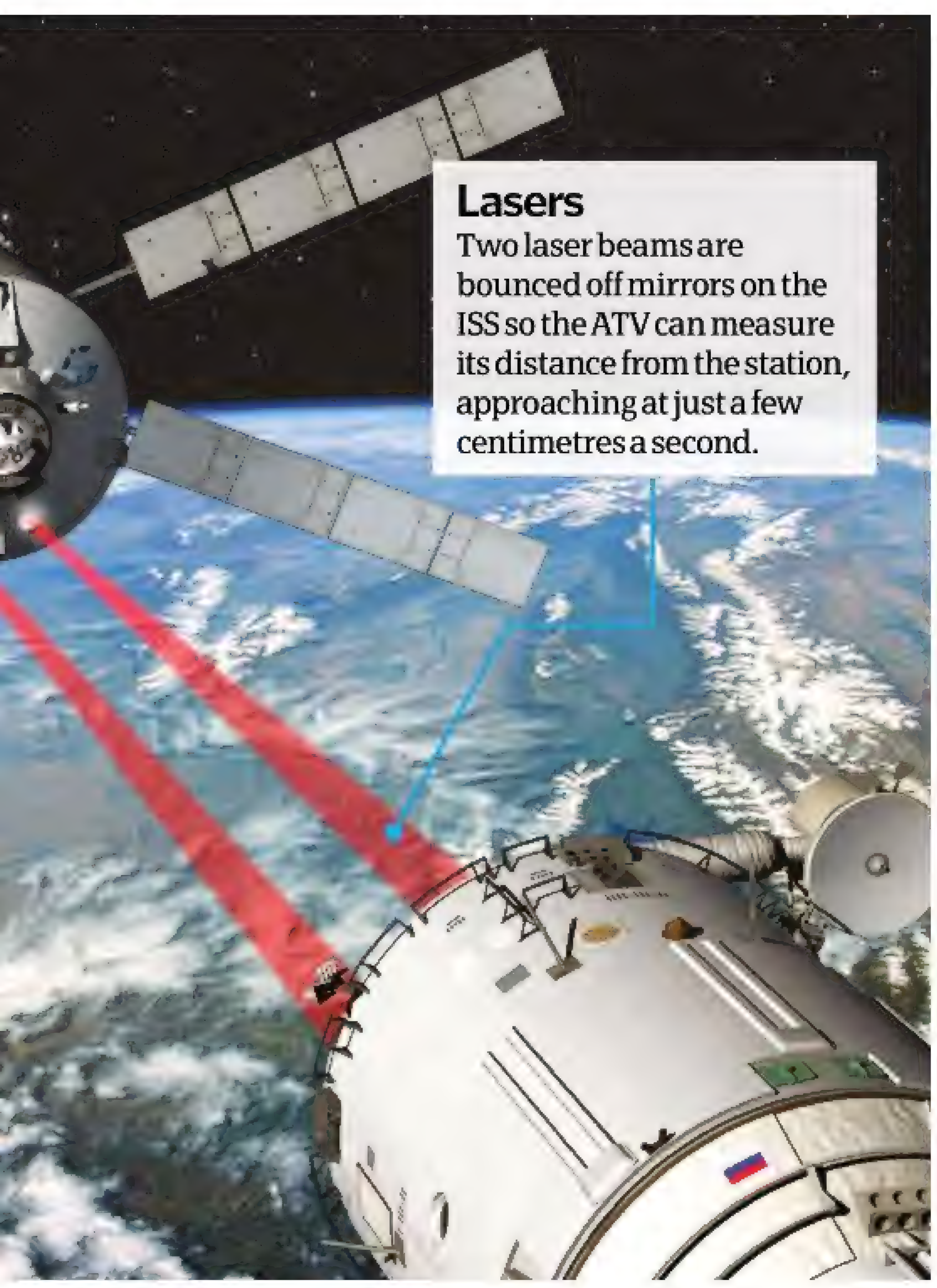
© NASA

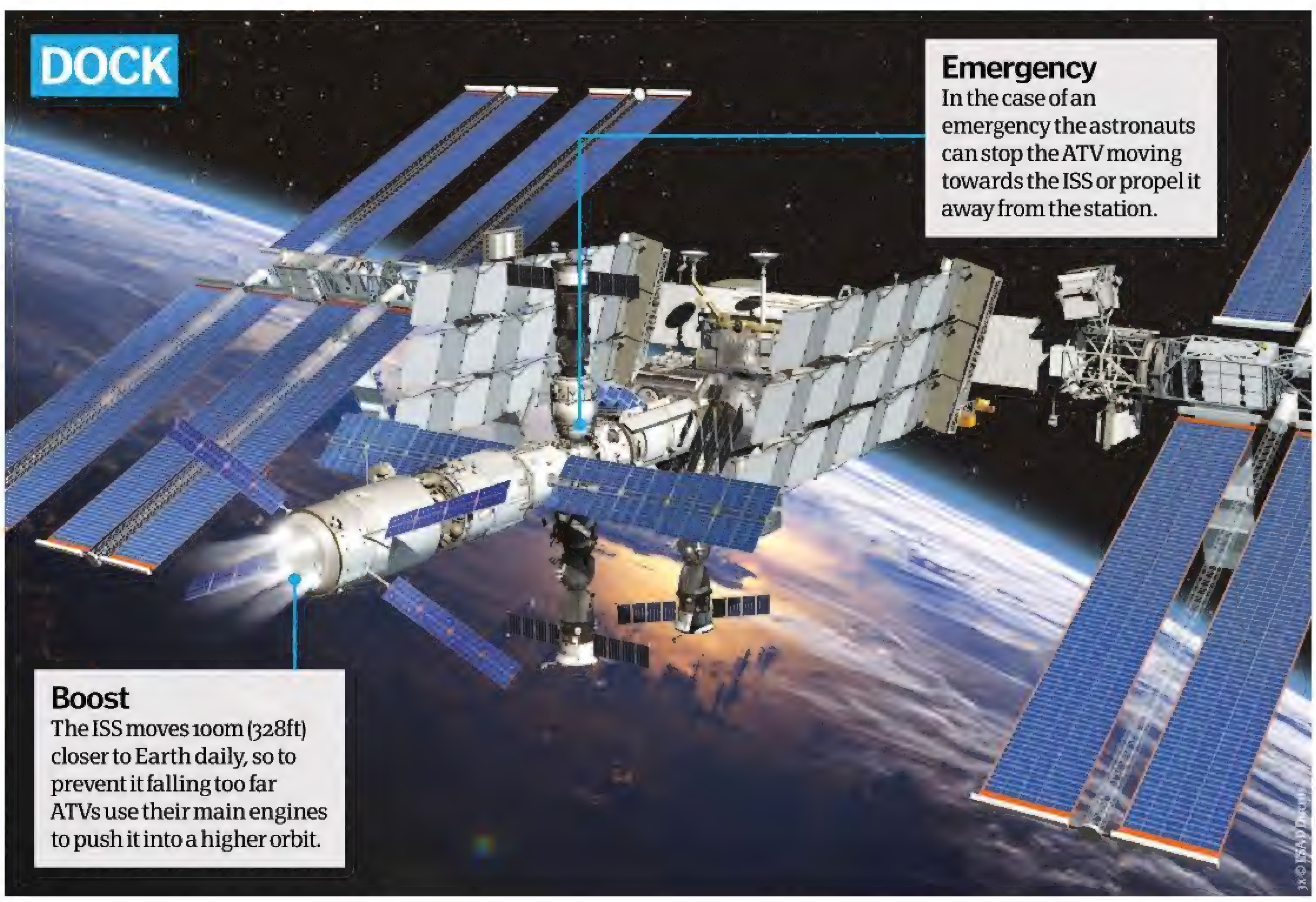
Other resupply vehicles

The ESA's automated transfer vehicle isn't the only spacecraft capable of taking supplies to the ISS. Since its launch, three other classes of spacecraft have been used to take cargo the 400 kilometres (250 miles) above Earth's surface to the station. The longest serving of these is Russia's Progress supply ship, which between 1978 and the present day has completed over 100 missions to Russia's Salyut 6, Salyut 7 and Mir space stations, as well as the ISS.

Succeeding Progress was the Italian-built multipurpose logistics module (MPLM), which was actually flown inside NASA's Space Shuttle and removed once the shuttle was docked to the space station. MPLMs were flown 12 times to the ISS, but one notable difference with the ATV is that they were brought back to Earth inside the Space Shuttle on every mission. The ATV and MPLM share some similarities, though, such as the pressurised cargo section, which is near identical on both vehicles.

The last and most recent resupply vehicle is the Japanese H-II transfer vehicle (HTV). It has completed one docking mission with the ISS to date, in late 2009, during which it spent 30 days attached to the station.





"Practical solar cells only became a reality thanks to the development of new semiconductors such as silicon"

Solar-powered spacecraft

Harnessing energy from the Sun, solar-powered space probes like Juno are taking environmentally friendly technology farther than ever before…

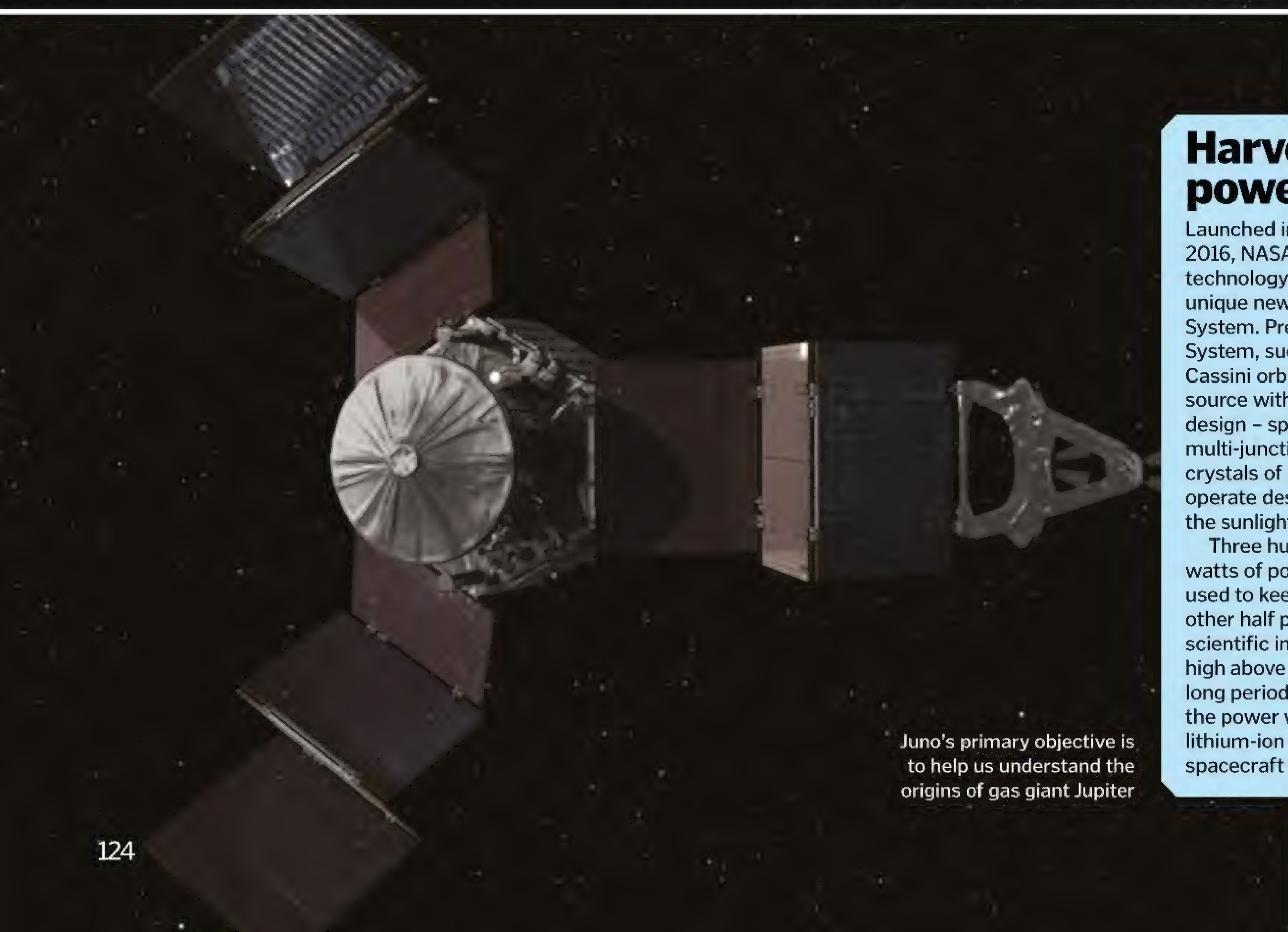
When you're launching a space probe to a distant planet, every kilogram counts. Every aspect of the design is a compromise between weight and scientific capability. With engine fuel at a premium, and batteries heavy and limited in life, solar cells – which draw their energy from the Sun itself – are an ideal way of generating power.

Solar cells rely on the photoelectric effect, which causes current to flow through certain materials when they are struck by light. The effect was discovered as early as the mid-1800s, and explained by Albert Einstein in 1905. It arises when individual photons of light striking a surface provide enough energy for charge-carrying subatomic electrons to break free of their individual atoms.

However, practical solar cells only became a reality thanks to the development of new semiconductor materials such as silicon and gallium arsenide in the mid-Fifties – just in time for them to be used in some of the earliest Earth satellites, and later in space probes.

For more far-flung missions, however, there's a stumbling block: the energy available from sunlight drops proportionally with distance from the star. As a result, solar energy has until recently only been a viable power source for missions to the inner Solar System (ie as far out as Mars). Advances in the efficiency of solar cells, along with the ability to pack and unfurl larger arrays (each carrying many separate cells) are starting to change that, as ably demonstrated by the Juno mission to Jupiter.

While most spacecraft still use solar cells purely for powering on-board systems, an increasing number are using them for propulsion too. Solar-electric, or 'ion engine', propulsion uses sunlight to split propellant into electrically charged ions and fire them out of the engine at extremely high speeds. The acceleration force this produces is tiny, but can be sustained for months or even years with just a small fuel supply. This makes it perfect for use on complex missions such as the Dawn probe currently touring the Asteroid Belt.



Coming online
Directly after launch, Juno only needed the power from two of its solar array panels; the others are needed as it travels farther from the Sun.

Juno's primary objective is to help us understand the origins of gas giant Jupiter

Harvesting solar power at Jupiter

Launched in August 2011 and arrived at Jupiter in 2016, NASA's Juno mission will push solar power technology to its limits in order to give us a unique new view of the largest planet in the Solar System. Previous probes to the outer Solar System, such as the Voyager missions and the Cassini orbiter, had to carry a radioactive power source with them, but advances in solar cell design – specifically the use of highly efficient multi-junction photoelectric materials made from crystals of gallium arsenide – will enable Juno to operate despite receiving just four per cent of the sunlight available at Earth.

Three huge solar arrays will generate 486 watts of power, roughly half of which will be used to keep the spacecraft warm, while the other half powers Juno's flight systems and scientific instruments. Juno's orbit will carry it high above Jupiter's poles, and as it will spend long periods of time in the gas giant's shadow, the power will also be used to charge a pair of lithium-ion batteries that should keep the spacecraft operating while it's in the dark.

KEY DATES
SOLAR POWER

1958 The US launches Vanguard 1 (right), a grapefruit-sized satellite and the first to be powered by the Sun.

1970 The Soviet Union's Lunokhod 1 is the first solar-powered rover to land on the Moon.

1998 NASA's Deep Space 1 mission (right) pioneers solar-electric propulsion, paving the way for missions like the Dawn probe.

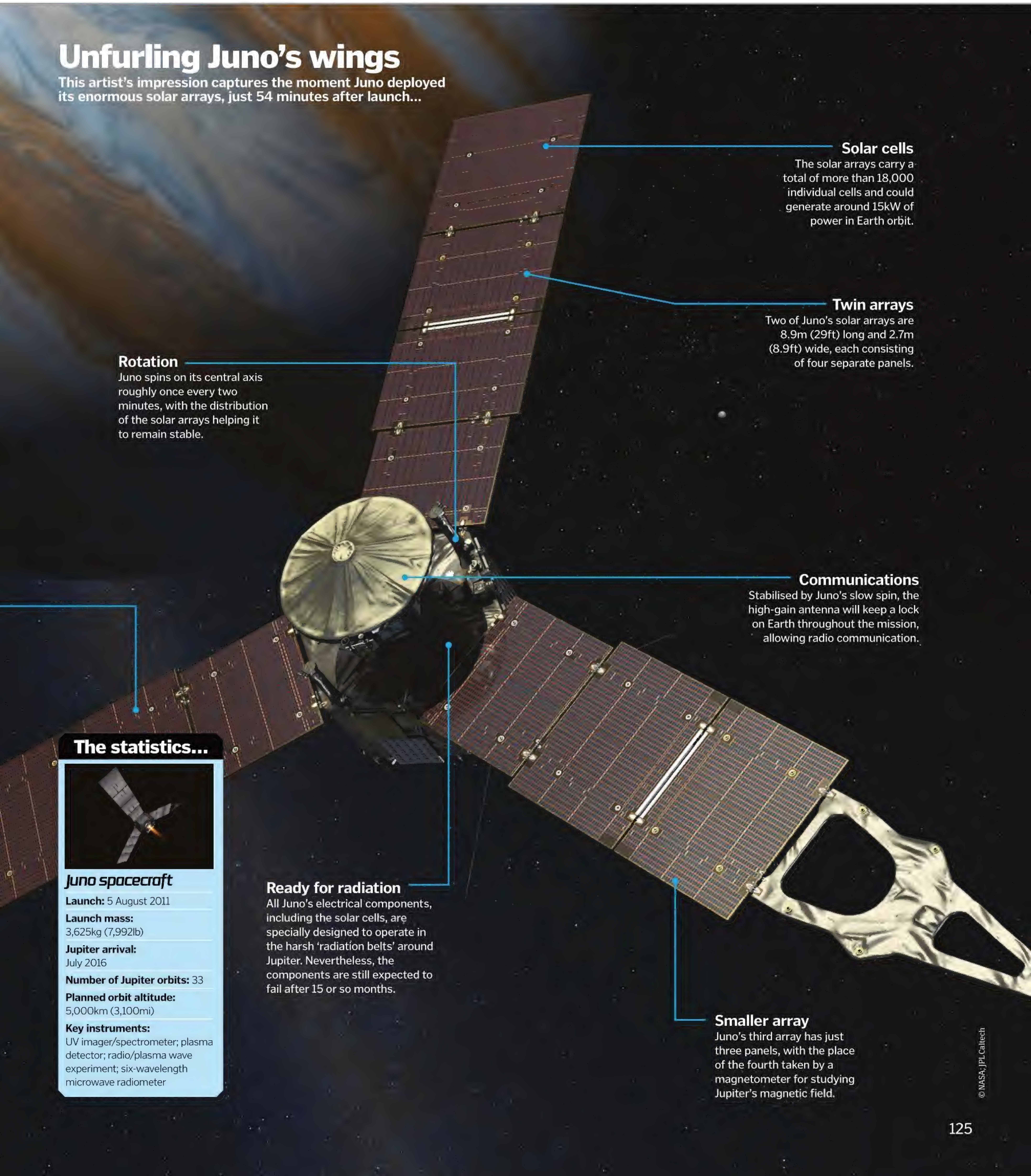
2010 JAXA's IKAROS spacecraft launches and successfully uses a solar sail as its main means of propulsion.

2011 Juno launches – the first spacecraft to use solar power in the outer Solar System.

DID YOU KNOW? *The solar cells on Vanguard 1 powered a transmitter that kept sending signals to Earth for almost seven years*

Unfurling Juno's wings

This artist's impression captures the moment Juno deployed its enormous solar arrays, just 54 minutes after launch...



Solar cells
The solar arrays carry a total of more than 18,000 individual cells and could generate around 15kW of power in Earth orbit.

Twin arrays
Two of Juno's solar arrays are 8.9m (29ft) long and 2.7m (8.9ft) wide, each consisting of four separate panels.

Rotation
Juno spins on its central axis roughly once every two minutes, with the distribution of the solar arrays helping it to remain stable.

Communications
Stabilised by Juno's slow spin, the high-gain antenna will keep a lock on Earth throughout the mission, allowing radio communication.

Ready for radiation
All Juno's electrical components, including the solar cells, are specially designed to operate in the harsh 'radiation belts' around Jupiter. Nevertheless, the components are still expected to fail after 15 or so months.

Smaller array
Juno's third array has just three panels, with the place of the fourth taken by a magnetometer for studying Jupiter's magnetic field.

The statistics...

Juno spacecraft

Launch: 5 August 2011

Launch mass: 3,625kg (7,992lb)

Jupiter arrival: July 2016

Number of Jupiter orbits: 33

Planned orbit altitude: 5,000km (3,100mi)

Key instruments: UV imager/spectrometer; plasma detector; radio/plasma wave experiment; six-wavelength microwave radiometer

Space planes

Discover how this new generation of aircraft will help us venture into space like never before…

Getting into space is no mean feat. Since the dawn of the Space Age we have relied on large, expensive and at times dangerous launch vehicles – namely rockets – to give payloads the necessary altitude and speed to get off our planet. Rockets use a huge amount of fuel, they're not reusable (hence their expense) and, perhaps most importantly, they have been known to fail with often disastrous consequences. But what if there was another way to travel off our world?

The holy grail of space exploration has long been to design some sort of vehicle that can launch from the ground, journey into space and return to Earth in one piece, with no expendable components and minimal risk. Space planes are one such idea that have been touted (and partially tested, as we'll explain later). They are vehicles that can take off from runways, travel into space and return to Earth. As their name would suggest they are essentially aeroplanes, but with a key difference: they are capable of operating both in the forgiving atmosphere of Earth and in the much harsher environment of space.

The first space plane of sorts was the rocket-powered X-15 jet in the Sixties. It remains the fastest manned vehicle ever launched and performed what is known as a suborbital flight, where a vehicle reaches the boundary of space and returns to Earth but does not enter orbit. Only two of the multitude of flights it performed technically reached space, but it lent weight to the concept of a space plane nonetheless.

Since then we have seen a few other pretenders take to the skies. NASA's Space Shuttle was a space plane in the sense that it glided back to Earth after completing operations in orbit, but as it launched on top of a rocket it was never regarded as a true space plane. The Soviet-built Buran spacecraft performed in much the same manner.

Now, in the coming years, we can expect to see more genuine space planes, each with a different design. The vehicle that has garnered the most attention in recent years has been

SpaceShipTwo

Virgin Galactic's eight-seater SpaceShipTwo space plane will take off from Virgin's own Spaceport America in New Mexico. It will be carried by a larger mothership – WhiteKnightTwo – before detaching in the upper atmosphere and using a rocket motor to propel itself into orbit. It will be used initially for space tourism, with 400 passengers already paid up, and will aim to begin commercial flights during 2019.

THE PIONEER

Lynx Mk 1

Unlike SpaceShipTwo, California-based XCOR's Lynx space plane lifts off and lands all by itself. Carrying one pilot and just one paying passenger, it can take off from a conventional runway, taking a steep climb of about 75 degrees before levelling out into suborbit and then returning to Earth. However, the plane's development was halted and the company went bankrupt in 2016.

THE CONTENDER

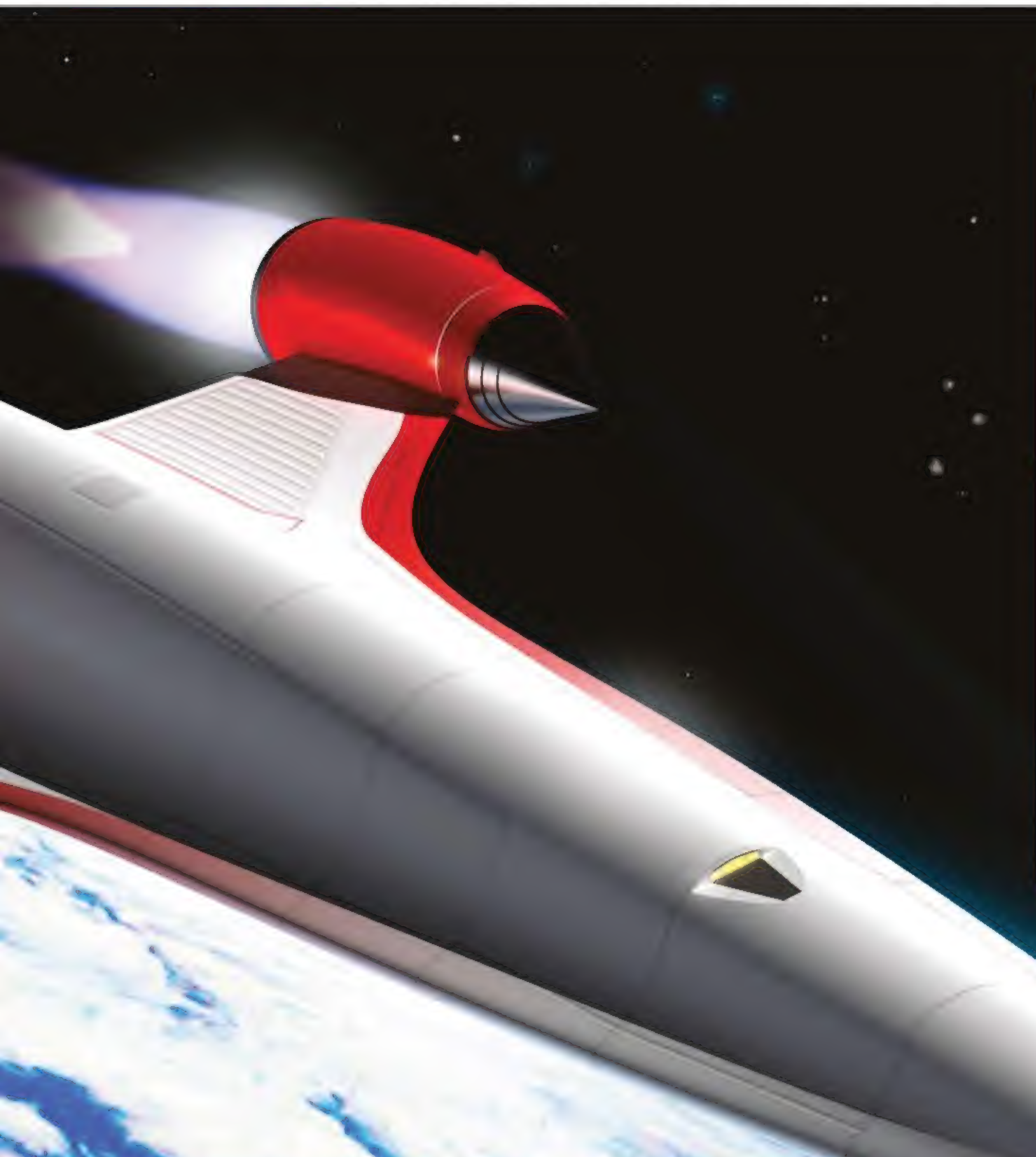
RECORD BREAKERS
PRIZE FLIGHT

$10MN

FIRST PRIVATE SPACEFLIGHT

In 2004, SpaceShipTwo's predecessor SpaceShipOne completed the first two-manned private spaceflights with pilots Brian Binnie and Mike Melvill, scooping the $10mn (£6.6mn) Ansari X Prize in the process.

DID YOU KNOW? *In the 1960s Pan Am opened registration for trips to the Moon in space planes, but they never materialised*



Spaceport vs airport

There are currently two major spaceports operating in the USA: the Mojave Air and Space Port in California and Spaceport America in New Mexico.

Spaceports must be able to support the added force associated with a space plane both at launch and landing. Thus, runways must be reinforced and also longer than conventional ones as space planes require a longer distance to accelerate and brake.

Spaceports also need training facilities to prepare their passengers for the rigours of spaceflight. Like rocket launch sites, spaceports benefit from being placed near the equator too. This allows the aircraft to get an added boost from the rotation of the Earth, making it slightly easier (and so less costly) to reach orbit than if they were launching farther away from the equator.

Spaceport America in New Mexico, USA, is where Virgin Galactic's SpaceShipTwo will be based

Dream Chaser

Sierra Nevada Corporation's Dream Chaser will launch on top of a rocket (probably an Atlas V) into orbit. It is expected to be able to dock with the ISS before gliding back to Earth, just like the Space Shuttle once did. In 2016 NASA awarded it a contract under CRS2.

★ THE NEXT SHUTTLE

Skylon

UK-based Reaction Engines Limited's Skylon plane could be a game-changer. It's intended to launch from a reinforced runway and return to Earth in a single unit and could carry 24 passengers. Development is ongoing and it may well be flying in the near future.

★ THE OUTSIDER

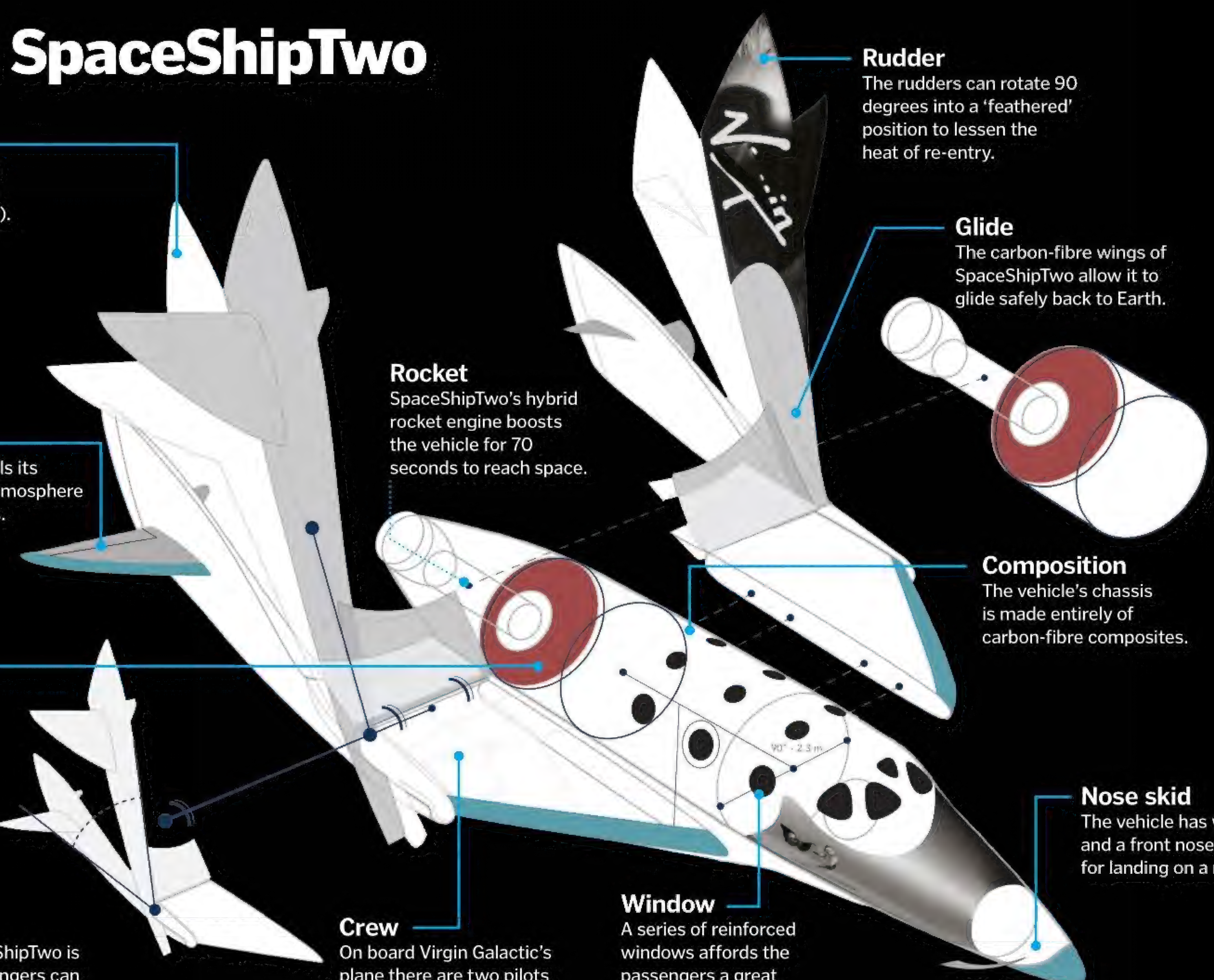
Virgin Galactic's SpaceShipTwo. This rocket-powered aeroplane is lifted into the sky by a larger mothership, WhiteKnightTwo, before separating and using its rocket engine to take six paying customers into space. Here, at a cost of $200,000 (£133,000) each – although this has recently risen to $250,000 (£166,000) – they experience six minutes of weightlessness.

It's not the only space plane in development though. A company called XCOR Aerospace has been quietly building its own vehicle, known as the Lynx aircraft, which will be able to take paying passengers into space. Unlike SpaceShipTwo it doesn't have a carrier vessel, and thus will be able to launch and land itself on a runway, bringing us a big step closer to the true vision of a space plane.

But aside from taking tourists on out-of-this-world trips, space planes have another more important use. It is expected, specifically with future versions of SpaceShipTwo and Lynx (eg SpaceShipThree and Lynx Mk 2), that they will eventually be able to launch payloads such as satellites into orbit. To do so they will reach their peak altitude before releasing a smaller spacecraft, which carries the payload into orbit. This would be a huge advancement for satellite operators, who at the moment must rely on rockets to get satellites off Earth but, in future, they could use aircraft at a much lower cost.

Space planes are also expected to fly passengers and crew not only into suborbit, but into full orbits around the Earth. One company hoping to do this is Sierra Nevada Corporation (SNC) with its Dream Chaser craft. With funding from NASA, they are hoping to launch this plane as the successor to the Space Shuttle. Travelling atop an Atlas V rocket, it will be capable of taking up to seven people into low Earth orbit

Inside SpaceShipTwo



History of space planes

How It Works picks out a few key dates in the evolution of space-faring vehicles

1959
The first rocket-powered plane, the North American X-15, makes its maiden flight.

1963
Pilot Joseph Walker takes the X-15 into space, making it the world's first space plane.

1981
The Space Shuttle, capable of taking a crew and cargo to and from orbit, launches for the first time.

1988
The Soviet-built Buran space shuttle makes its first and only flight into space.

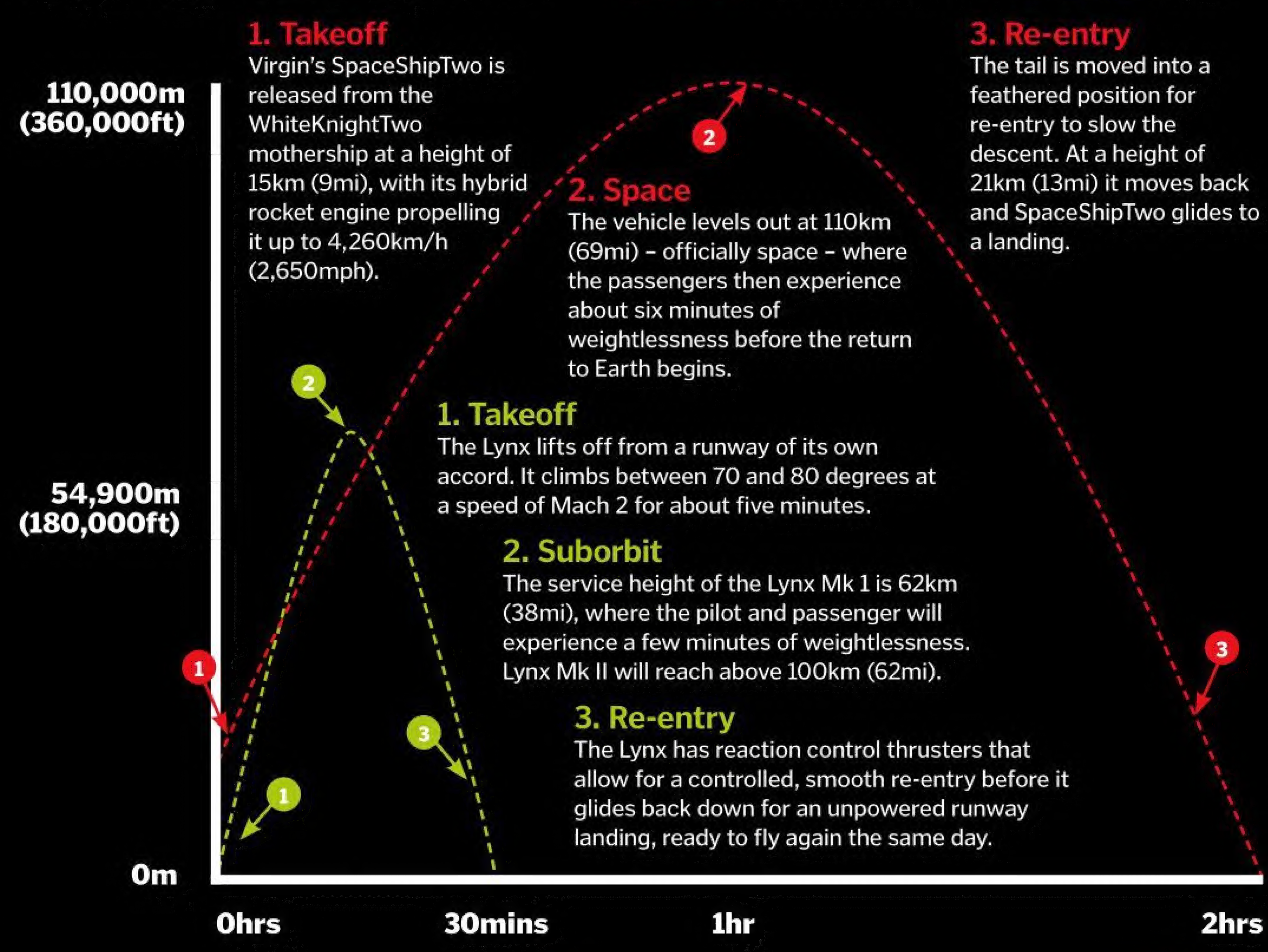
(LEO) where they could dock with the International Space Station (ISS). This would provide the ISS with another means of transporting crews to the station aside from Russia's Soyuz spacecraft. After leaving the ISS, the Dream Chaser will fly back down to Earth much like a regular aeroplane.

Another vehicle designed to take both people and cargo into orbit – but which is further behind in its development than the Dream Chaser – is the Skylon space plane. Currently being developed by UK-based Reaction Engines Limited (REL), Skylon could be a revolution in space travel if it ever flies, as it is larger than SpaceShipTwo and boasts a much bigger hold.

REL has stated that when Skylon lifts off – hopefully at some point towards the end of this decade – it will reduce the cost of taking a payload into space from £15,000 ($23,000) to just £650 ($990) per kilogram. It could also transport as many as 24 people off our planet at a time. The vehicle will use a hybrid air-breathing rocket engine to reach orbit in a single stage before gliding back to the surface.

The goal of space planes is, ultimately, to reduce the cost of going to space. While the early flights of SpaceShipTwo and Lynx will predominantly be centred around tourism, it is fully expected that space-faring aircraft will be used to take useful cargo into orbit in the not-too-distant future. Making space more accessible will enable us to operate more efficiently in Earth orbit, while the tourism aspect will help to fund those endeavours. Indeed, companies like Virgin Galactic have said that, while the first few hundred tourist flights will be quite expensive, future tickets should become much more affordable.

Flying into space



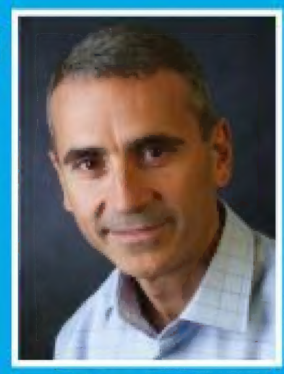
2004
Scaled Composites' space plane completes the first privately funded human spaceflight.

2005
Richard Branson's Virgin Galactic acquires Scaled Composites and then begins work on SpaceShipTwo.

2008
XCOR Aerospace announces that it will begin development of the Lynx space plane.

2013
SpaceShipTwo makes its first rocket-powered flight, a key step to full launches.

Steve Isakowitz



The Executive Vice President and Chief Technology Officer at Virgin Galactic tells us why we should be excited about space planes

Why are space planes important?
Space travel is one of the only transportation modes where we throw everything away every time we fly. What we're trying to achieve is the ability to fly these suborbital flights, bring down the [space plane], turn it around quickly and re-fly it over and over again.

Will tickets to space become cheaper?
That is our goal, to open up the space frontier for anybody who has the desire to go there. Once we prove this second-generation vehicle [SpaceShipOne was the first] we expect to have a third, fourth and fifth generation that will continue to drive down costs and improve reliability.

What differentiates SpaceShipTwo from the Lynx?
We're giving people the opportunity to unbuckle from their seats and have the opportunity to float within the cabin and experience both the euphoria of zero-g and looking out the windows and seeing an incredible view of Earth.

What can we expect in the future?
One of the things we keep our eyes on is point-to-point travel, the idea of flying between two very distant cities but at a fraction of the time that it takes a commercial airline to do it. You might be able to fly from Tokyo to Los Angeles in a third of the time that an airline currently does. That could be a huge industry that one could tap into [sometime in this decade] with some of the very technologies that we're trying to develop.

UNMANNED AERIAL VEHICLES

HOW IT WORKS

FLYING AN F-35

BOOK OF
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Come face to face with some of the world's most powerful military gunships and aircraft

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Take a look inside commercial aircraft, from private jets and hot air balloons to personal drones and gliders

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Survey the outer limits of our universe with the spacecraft that investigate alien worlds and stars

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